CLAUDIAN AQUEDUCT (ROME), BUILT IN 50 A.D. (*Frontispiece.*)

WATER-SUPPLY.

(CONSIDERED PRINCIPALLY FROM A SANITARY STANDPOINT.)

BY

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THIRD EDITION, REWRITTEN.

FIRST THOUSAND.

NEW YORK:
JOHN WILEY & SONS.
LONDON: CHAPMAN & HALL, LIMITED.
1902.

ROBERT DRUMMOND, PRINTER, NEW YORK

PREFACE.

So much material has been added to our stock of general knowledge upon the subject of "Water-supply" since the appearance of the last edition of this book that it was found necessary to practically rewrite no inconsiderable portions of the original text. The chapters upon the "Chemical and Bacteriological Examination of Water" have been omitted from the present edition, for the reason that they have been published separately in book form for the more convenient use of students.

The writer hopes and believes that acknowledgment has been given whenever material has been extracted from either the published works or private notes of other authors, but he finds himself under obligations to so many persons, both here and in Europe, for courtesies extended and information furnished, that he is quite hopeless of properly recognizing them.

WILLIAM P. MASON.

RENSSELAER POLYTECHNIC INSTITUTE,
TROY, N. Y., February, 1902.

CONTENTS

WATER-SUPPLY.

CHAPTER I.

INTRODUCTORY.

FROM remote antiquity the highest value has been set upon an abundant and pure water-supply. Centres of population sprang up in ancient times around those points where it was readily available, and great expenditures of labor and treasure were made to carry it to places where it was not naturally plenty. Not only was a generous daily *per capita* allowance sought for, but we note in the centuries gone by unmistakable evidences of a keen appreciation of the dangers lurking in a polluted supply; and upon this point many of the ignorant consumers of our own day and generation would be benefited did they consult the wisdom of the past.

Hippocrates, for instance, who wrote upon the value of pure water some four hundred years before the beginning of our era, advised boiling and filtering a polluted water before using it for drinking—advice which all must consider entirely "up to date."

He further believed that the consumption of swamp-water, in the raw state, produced enlargement of the spleen.

Pliny (A.D. 70) in his "Natural History" (book XXXI, chapters I to VI) devotes large space to the discussion of

potable water, and thus speaks of one of the numerous supplies of Rome, which, by the way, is a water in use to-day:

"Among the blessings conferred on the city by the bounty of the gods is the water of the Marcia, the cleanest of all the waters in the world, distinguished for coolness and salubrity."

Libavius in 1595 refers to Pliny's work, and adds the curious suggestion that the weight of a water is proportionate to its potability.

During the Middle Ages it was observed that water sometimes became poisonous through being distributed in lead pipes.

Although Lascaris, who died in 1493, did not recognize the power of water to intensify and spread certain epidemics, it is interesting to observe that his teachings upon the origin of disease came very near the germ theory of the present day.

The following from *The Hospital* is worth preserving as showing how our ancestors regarded the question of water-drinking:

"It needed a very bold man to resist the medical testimony of three centuries ago against water-drinking. Few writers can be found to say a good word for it. One or two only are concerned to maintain that 'when begun in early life it may be pretty freely drunk with impunity,' and they quote the curious instance given by Sir Thomas Elyot in his 'Castle of Health,' 1541, of the Cornish men, 'many of the poorest sort, which never, or very seldom, drink any other drink, be notwithstanding strong of body, and like and live well until they be of great age.' Thomas Cogan, the medical schoolmaster of Manchester fame, confessed in his 'Haven of Health,' 1589, designed for the use of the students, that he knew some who drink cold water at night or fasting in the morning without hurt; and Dr. James Hart, writing about fifty years later, could even claim among his acquaintances 'some honorable and worshipful ladies who drink little other drink, and yet

enjoy more perfect health than most of them that drink of the strongest.' Sir Thomas Elyot himself is very certain, in spite of the Cornish men, that there be in water causes of divers diseases, as of swelling of the spleen and liver. He complains oddly, also, that 'it flitteth and swimmeth,' and concludes that 'to young men, and them that be of hot complexion, it does less harm, and sometimes it profiteth, but to them that are feeble, old, and melancholy it is not convenient.' But the most formal indictment against water is that of Venner, who, writing in 1622, ponderously pronounces to dwellers in cold countries 'it doth very greatly deject their appetites, destroy the natural heat and overthrow the strength of the stomach, and, consequently confounding the concoction, is the cause of crudities, fluctuations, and windiness in the body.' "

Much the larger undertakings connected with ancient water-supply were those built entirely for, or at least in connection with, general systems of irrigation. "The extent of some of these great hydraulic works can be conjectured from the ruins remaining. Lake Moeris, in Egypt, was constructed at least 2000 years before Christ. Its dimensions were sufficient to regulate the annual inundation of the Nile, receiving the surplus waters when there was danger of a flood, and supply the needed deficiency when the river reached a stage which would not irrigate the crops. This, with other large reservoirs of flood-waters, enabled a population of 20,000,000 to exist in the valley of the Nile, while it now supports barely one fourth of the number.

"In ancient times the valleys of the Euphrates and Tigris, now almost a desert, were densely populated. Four thousand years ago the rulers of Assyria had converted those sterile plains and valleys into gardens of extreme productiveness by the construction of immense artificial lakes for the conservation of the flood-waters of the rivers, and great distributing-canals for irrigation. One of these canals, supplied by the Tigris,

was over 400 miles long and from 200 to 400 feet broad, with sufficient depth for the navigation of the vessels of that time.*

"In India tanks, reservoirs, and irrigating-canals were constructed many centuries before the Christian era, and a great part of that country was kept in the highest state of cultivation. Some of the tanks or artificial lakes covered many square miles, and were often fifty feet in depth.

"Evidences exist in New Mexico and Arizona that in prehistoric times a race now extinct had extensive irrigation-works and cultivated large areas." (Wyckoff.)

Professor F. H. Cushing advises the author of his discovery of ancient reservoirs of large size in southern Arizona.

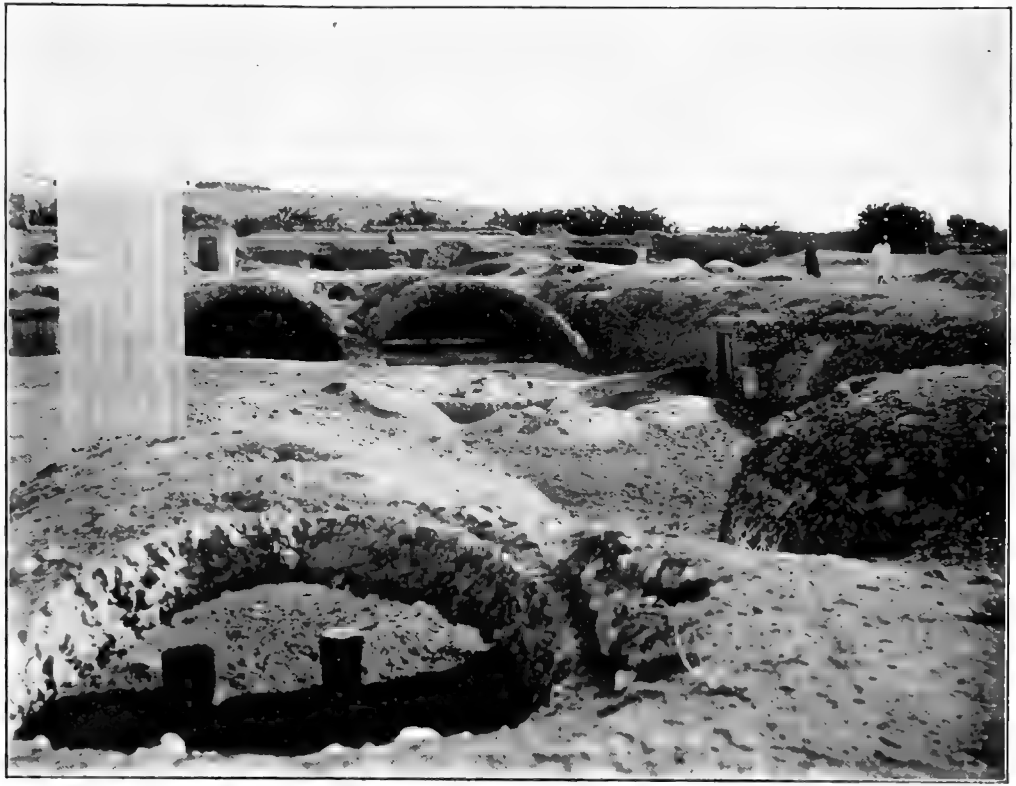
On the site of ancient Carthage there are still to be seen the great cisterns for storage of water, eighteen in number, and each about one hundred feet long, twenty feet wide, and nearly twenty feet deep. They were originally covered with earth, and to-day are in marvellously good repair. They lie in two long rows and empty into a common gallery situated between the rows. They belonged to the ancient or Punic city.†

Drinking-water was supplied to ancient Carthage from a spring in the Zaghoun Mountains some sixty kilometres to the south. The channel way, which the writer found to be only ten inches square in section, contoured the hillsides for considerable distances, at times went under ground, and on approaching the coast was carried on arches of a magnitude seemingly out of proportion to so small a channel. From ten to fifteen kilometres of the old aqueduct yet remain. See illustration opposite.

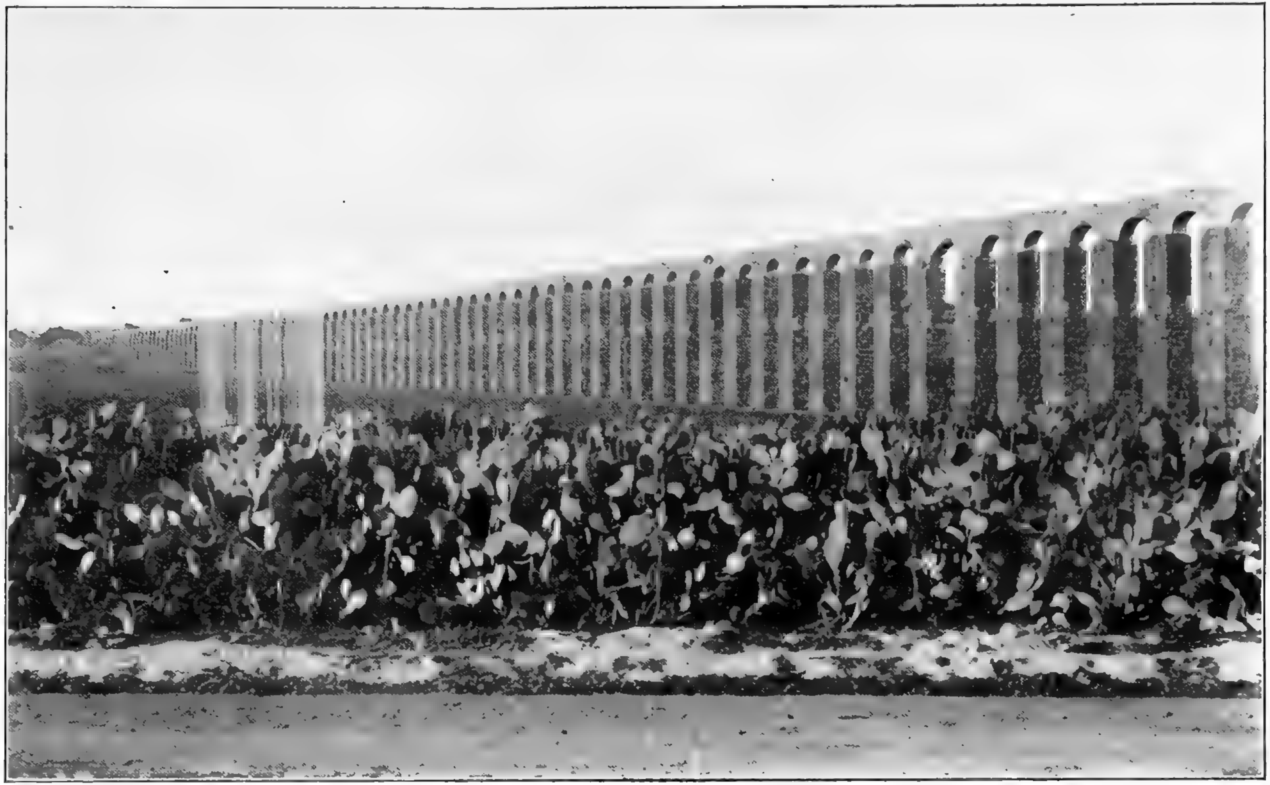
"Amongst the wonderful monuments of the former greatness of the Singhalese people must be mentioned the ruined

* The Nahrawan Canal. It is of great antiquity, and its former importance is shown by the ruins situated along its course.

† See "Carthage and Carthaginians," by Bosworth Smith.



THE CISTERNS AT CARTHAGE. ALL THAT IS LEFT OF THE ANCIENT CITY.



AQUEDUCT NEAR TUNIS, LEADING TO ANCIENT CARTHAGE.

tanks, with which scarcely anything of a similar kind, whether ancient or modern, can be compared. Thirty colossal reservoirs and about seven hundred smaller tanks still exist, though for the most part in ruins. In February, 1888, the largest and most important tank in Ceylon, that of Kalawewa, was, after four years of labor, completely restored. It was built 460 A.D. to supply Anuradhapura with water, but has been ruinous for centuries. Now again it contains an area of seven square miles of water, twenty feet deep, and supplies smaller tanks more than fifty miles distant." *

When we reflect that these great works of antiquity were accomplished without the aid of steam, electricity, or explosives, we are impressed with the belief that, in intelligent perseverance at least, "there were giants in those days." Our respect does not lessen when we contemplate the extent of the supply of water poured into the "Eternal City."

The following is freely taken from Forbes's lecture on the Roman aqueducts:

ROMAN AQUEDUCTS, ARRANGED IN CHRONOLOGICAL ORDER.

	Date of Construction.		Length.	
Appia	312	B.C.	11	miles
Anio Vetus	272	"	43	"
Marcia	145	"	61	"
Herculea branch	—		3	"
Tepula	126	"	13	"
Julia	34	"	15	"
Virgo	21	"	14	"
Augusta	10	A.D.	6	"
Alsietina	10	"	22	"
Claudia	50	"	46	"
Anio Novus	52	"	58	"
Neronian branch	97	"	2	"

* Chambers's Encyclopædia, iii. 80.

	Date of Construction.	Length.
Traiana	109 to 200 A.D.	42 miles
Hadriana	117 to 1585 "	15 "
Aurelia	162 "	16 "
Severiana	200 "	10 "
Antoniniana branch	215 "	3 "
Sabina—Augusta	130 to 300 "	15 "
Alexandrina	226 "	15 "

(The miles above given are Roman, of 4854 feet. The entire length of the aqueducts in English miles would be 381.)

It has been calculated that, altogether, the supply was 332,306,624 gallons daily, which would have been over 332 gallons *per capita* upon a basis of a population of one million. This calculation, however, has been based upon very indifferent data furnished by Prony in 1817. As Mr. Clemens Herschel has lately shown, a much more probable figure for the daily water consumption of the world's capital should read thirty-two million U. S. gallons.

Notwithstanding that some of the Roman aqueducts were damaged during the wars of the sixth and seventh centuries, the supply did not entirely cease until the fourteenth century, when Rome was abandoned by the papal court. In the present day four of the ancient sources still supply the city with water.

Of the imposing lines of arches which stalk across the Campagna none is more interesting than the stately Claudian aqueduct. (See frontispiece.)

Speaking of it, Pliny says: "The preceding aqueducts have all been surpassed by the costly work more recently commenced by the Emperor Caius and completed by Claudius. The sum expended on these works was 350,000,000 of sesterces." *

Near the city the Claudian arches were filled up by

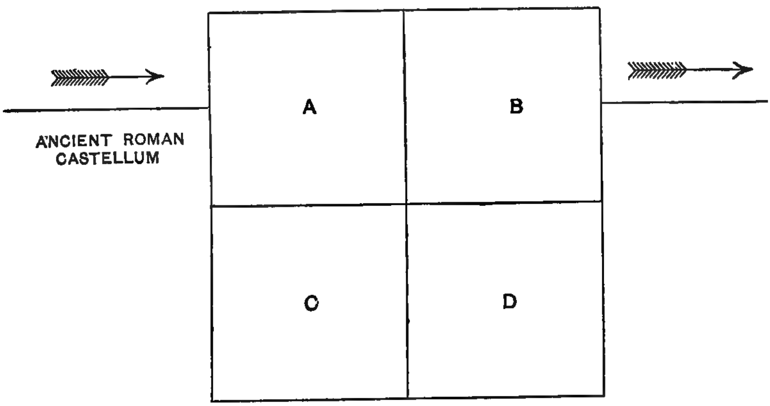
* About 12,700,000 dollars.

Aurelian, and made to do duty as part of the city wall, the great gateway permitting passage at this point being known as the Porta Maggiore.

It is curious to observe that waters from different sources were carried in separate channelways upon the same arches.

Speaking of the Marcia, Tepula, and Julia waters, Frontinus says: "The three are carried on the same arcade, the highest being the Julia, then the Tepula, and lowest the Marcia." Near the Porta Maggiore the three channels are still distinctly to be seen.

It remains to say a word about the "castella" so often found along the courses of the Roman aqueducts. Forbes calls them "filtering-places," but such they could not have been—at least in the modern acceptation of the expression. They varied in size and in the number of their chambers, some having but four, while others numbered as many as twelve, compartments. One of the smallest size is here illustrated:



ANCIENT ROMAN CASTELLUM

The water entered chamber *A* and passed by means of holes in the floor into *C*, thence through openings in the wall into *D*, from which it rose through holes in the floor into *B*, and then passed on to Rome. A breaking of undue "head" would take place in the "castellum," as is accomplished in a

more modern fashion at Vienna to-day; * but the real benefit derived from the construction of these chambers was probably the opportunity given for sedimentation.

Thus Frontinus says: "At the seventh mile, on the Via Latina, the Marcia, Tepula, and Julia are taken into a covered 'filtering-place,' where, as though breathing again after their course, they deposit mud."

So far as quality of water is concerned it is probably true that the ancient public supplies were better than the average of what is furnished to our cities to-day; for the reason that pumping was unknown and the water-purveyors were of necessity driven to distant and purer sources to the exclusion of local rivers which lay too low to be utilized.

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* At Vienna the aqueduct has a fall of 11,000 feet in the first 10 miles, and 10 feet per mile the remainder of the way. It is about 60 miles long. The "head" is throttled by gates, every 100 feet of fall on the upper section. See *Engineering News*, Nov. 29, 1894.

CHAPTER II.

DRINKING-WATER AND DISEASE.

IN that excellent treatise upon "Water-supplies and Inland Waters" issued by the Massachusetts State Board of Health, waters are classified as "normal" and "polluted," the former being such as are free from addition, directly or indirectly, of either sewage or industrial waste.

The relation of "normal" waters, as a class, to sanitary science constitutes a subject by itself, and one shrouded in much confessed ignorance and conflicting testimony, as is instanced by the doubt we entertain of the effect of "peaty water" upon the human organism.

Bog-waters in Ireland, especially those of Lough Sheighs in the county of Cavan, and of Lough Neagh, have long been used for the treatment of skin-diseases. The mineral waters of Askern, in Yorkshire, England, are about saturated with peaty material from the neighboring bogs, and have for many years been successfully used in the treatment of chronic rheumatism and skin-diseases.

Bothamley thinks it not improbable that the dissolved peaty matter is the curative agent in these waters.*

"Certain affluents of the Orinoco and Amazon have what are called black waters (*aquas negras*). When seen in mass, they are of a coffee-brown or of a greenish black. In the shade they are almost black, but in a glass they are brownish

* J. Chem. Soc., lxiii. 696.

yellow, though very transparent. They have no disagreeable taste, and are preferred for drinking.

"The samples analyzed contain, in parts per million, 28 of humic compounds, 1 of lime, 16 of total solids, and no nitrates. The residue contained silica, alumina, iron, manganese, and potassium. The waters do not undergo any chemical change on keeping." *

This ability to "keep well" is very frequently observed in brown waters, but it is by no means universal, nor does it seem to be a necessary characteristic indicating potability.

In writing to the author regarding the water of the Dismal Swamp of Virginia, Surgeon-General J. R. Tryon, of the U. S. Navy, says:

"I beg to enclose herewith copy of analysis made of Lake Drummond (Dismal Swamp) water in October, 1891, at the Naval Museum of Hygiene.

"This has always been considered a very pure water, and before the general adoption of condensers was much used for naval vessels. The bureau has no special data bearing upon the relation to disease with the use of the class of waters referred to," i.e., "peaty" waters.

ANALYSIS OF LAKE DRUMMOND WATER.

(Parts per Million.)

Color	Yellow
Odor	Sweetish
Turbidity	None
Sediment	Very slight
Residue on evaporation	294.0
Loss on ignition	258.0
Fixed solids	36.0
Free ammonia	.016
Albuminoid ammonia	1.75

* *Chem. News*, lviii. 305.

Nitrogen as nitrites	None
Nitrogen as nitrates	5.00
Chlorine	1.50
Hardness	49.3

Many of the surface-waters of Massachusetts are colored brown, especially that of the Acushnet River, supplying the town of New Bedford. Experiments made with this water showed that its dissolved nitrogenous matter remained permanent for months without the development of "free ammonia," or other indications of decay.*

Writing to the author regarding sundry peaty waters which had come within his experience, Dr. Charles Smart, of the army, says:

"No bad effect was attributed to any of these waters. I had one, however, which, with the characters just mentioned, showed many infusoria, rotifers, and amœboid masses such as are seen in marsh-waters; but for these last characteristics I should have called it a peaty water. As it was a well-water, I suspected vegetable *débris* in the well, and directed investigation, when quite a depth of compacted dead leaves was taken out. This water was considered to have caused diarrhœa, and its use had been abandoned for some time before the sample was taken for investigation."

As illustrating the undesirable character of some swamp-waters, the celebrated case of the ship Argo may be called to mind; an incident too often recited to bear repetition here.†

A more modern illustration is afforded by the experience of Long Branch, N. J., in August, 1887. The town took its water-supply from Cranberry Creek, which rises in a cypress swamp about four miles to the west. It happened that at the time mentioned the dam on this creek gave way and the water, which is very heavily charged with peaty matter, was

* Mass. Bd. Health, 1890, 547. † Parke's "Hygiene."

pumped directly into the mains without having the customary interval for sedimentation, clarification, and bleaching. The result was an epidemic of diarrhœa, which affected numbers of the summer visitors, and filled the New York papers with long articles of complaint.

An examination of the water, made at the time by Prof. A. R. Leeds, showed that out of 187 parts per million of total solids 92 parts were organic, and nearly the whole of this was oxidizable by potassium permanganate. Filtration remedied the evil, and no such trouble has since obtained.

It has been the author's fortune to meet with but few cases of illness traceable to peaty waters, and in all such instances the patients suffered from a mild and transient form of diarrhœa, caused by water from a low-lying, shallow lake or pond, surrounded by low wooded banks. Whatever be the morbific principle of such waters, it appears to be removed by suitable filtration.

Tidy is inclined to look with doubt upon the dictum that peaty water induces diarrhœa, for he finds the death-rate from such cause lower than the average in certain towns whose water-supplies are exceedingly peaty in character, although he admits that in some Irish towns furnished with peaty water the death-rate from diarrhœa is excessive.*

Mrs. E. H. Richards very properly points out that such peaty waters as are found unwholesome may owe their toxic qualities to the presence of materials other than the brown coloring matter.

When we dwell upon the fact that the milder enteric disorders rarely get into the "death-rate," and that visiting strangers may suffer from a cause to which the acclimated natives are not susceptible, we appreciate that such data as Tidy furnishes do but emphasize what we believe to be a fact,

* J. Chem. Soc., xxxvii. 319.

that in dealing with peaty water we must consider it as largely an unknown quantity, possibly entirely harmless, but also the possible centre of much trouble, especially if the amount of organic matter present be large. Even the same water may not at all times be equally potable, for, as J. W. Mallet has well said: "It seems quite conceivable that a water containing organic matter of any kind may be harmless at one time and harmful at another, when perhaps a different stage of fermentation or putrefactive change may have been entered upon, and special organisms may have made their appearance or entered upon a new phase of existence. Thus there might possibly be safety in drinking a peaty water, or water filtered through beds of dead forest leaves, when fresh; danger when, after a certain amount of atmospheric exposure, bacterial organisms had become developed; and safety, again, perhaps, after the growth of such organisms had fallen off, and more or less of the available organic matter had been consumed." *

When, therefore, the question arises as to the advisability of introducing a peaty water as a town supply, the possibly unsatisfactory character of the same must always be borne in mind, and the municipal authorities should be prepared for the probable necessity of constructing a filtering-plant. Moreover, the likelihood of a filter-plant being required will increase as the years go by, for the people are fast inclining towards a demand for a clear and bright water as well as one that is potable. Furthermore, a distinction should be always drawn between a flowing water carrying fresh peaty material in solution and a water derived from a stagnant swamp. "In certain cases it may be a fact that the algæ decay rapidly, but that new growth absorbs the products of decomposition, so that they do not accumulate in the water. Shallow, stagnant

* Schröder has observed that peat, particularly if it be of acid reaction, possesses the power of quickly destroying the cholera germ. He found the spirillum killed after an exposure of five hours to peat-dust.—J. Soc. Chem. Ind., xiii. 538.

bodies of water, which in the heat of summer are full of vegetable and animal life, become in time foul, because decay gets ahead of growth and the products of decomposition accumulate."

"Malaria and Drinking-water" is the title of papers now frequently found in our sanitary press, and it would seem that those who contend that "malaqua" should be substituted for the less appropriate term "malaria" have presented a strong case. Among those whose opinions upon the question are entitled to great respect is Dr. Charles Smart, U. S. Army.*

Surface-waters and shallow well-waters from "malarious" sections of the country have been shown to be productive of fever by an accumulation of testimony that is difficult to resist. The State Board of Health of North Carolina has been particularly active in securing evidence of this kind, and the following is a single instance of many that might be quoted: †

Hawkinsville, Ga., is a manufacturing town situated in a district where "malaria was so common that its inhabitants got into the habit of expecting to have a few chills every fall, as a matter of course. The water used, until recent years, was drawn from shallow wells, which undoubtedly received the surface drainage of the country. In order to get a larger supply of water one of the cotton-factories put down an artesian well. The autumn following, the people who had used this water exclusively during the season were gratified to find that they escaped from the expected chills. The result was that a sufficient number of artesian wells were sunk to supply the entire town, and the place has been free from malaria ever since."

It is unnecessary to multiply citations such as the fore-

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* Surgeon-General's Report, 1896, p. 79.

† Bul. N. C. Board of Health, Aug. 1897.

going;* suffice it to say that they could be made both numerous and convincing, and that they support the conclusions reached by Laveran some years ago:

"1st. There have been observed cases in which, in the same locality, persons living in identical conditions, but using drinking-waters from different sources, the one group being attacked in a large proportion, while the other group of persons are scarcely affected at all.

"2d. In certain otherwise unhealthy localities the paludal fevers have been seen to disappear by supplying pure drinking-water instead of the previously used stagnant waters.

"3d. In localities otherwise healthy one can contract intermittent fever by drinking water from an unhealthy locality.

"4th. Travellers in malarial countries have found that on boiling their drinking-water they escape the disease in a large proportion of cases."

It is proper to note here that the recent investigators, Celli, Manson, Grassi, and others, have proven that "malaria" results also from the bites of infected mosquitoes; and Celli lays especial stress upon the point that, contrary to popular belief, a swamp containing a mixture of sea and fresh water is not "malarious" because the salt destroys the larvæ of the insects.†

The "mosquito-malaria" theory has undoubtedly been lifted out of the stage of speculation. The experiments, conducted in London, upon Dr. Manson's son, which resulted in the production of fever through the bites of infected mosquitoes imported from Rome, establish the relationship between the insects and the disease; but it would be very unwise to entirely discard the accumulated data of the past, which show that

* See also *Brooklyn Med. J.*, Jan. 1893; *Sanitarian*, Aug. 1892; *Med. Record*, Sept. 15, 1894; Fifth and Sixth Biennial Reports, N. C. State Board of Health.

† J. Sanitary Institute, xxi. 617.

another cause for the malady lies in the character of the local water.

In the report of the Michigan State Board of Health, 1882, the proposition is made by Dr. Mulhern that the presence of decomposing sawdust in water is a cause of malaria. Whether or not this can be proven, it is unquestionably true that such material can render water highly objectionable. In certain portions of Michigan the enormous lumber trade has forced upon the people sanitary problems of very unusual character.

"In some places large areas of low ground, but little above the water-level of the adjacent lake or river, have been built up with sawdust, until sufficient elevation has been secured to build houses on these made-lands. To such an extent have whole blocks and streets been built up with this sawmill waste that the epithet 'sawdust city' applies with singular force to some of the most enterprising business centres.

"Take as an example the water from an open well in Grand Haven, excavated in a sawdust area, the well 7 or 8 feet deep, and the water-level only 3 feet below the surface. The water contained 260 parts solids in 1,000,000 parts of water, 170 parts being volatile and organic. It contained 1.5 parts free ammonia and 1 part albuminoid ammonia. It contained so much combustible matter and nitrates in solution that on evaporating a litre in a large platinum basin and heating the residue at one edge a brisk deflagration spread over the whole dish.

"1. These sawdust waters all contain an amount of organic matter sufficient to condemn them for potable and culinary use.

"2. They all contain resinous extractive matter in solution.

"3. They all contain nitrogenous material capable of yielding albuminoid ammonia greatly in excess of the sanitary limit.

"4. They contain all the chemical elements necessary to sustain low forms of plant-life.

"5. In the presence of so large an amount of organic matter and the chemicals of plant-life these waters may become dangerous by nourishing and reproducing the germs of epidemic disease, should they find lodgment therein."

Odors which at times occur in water, and which are variously described as "musty," "fishy," "cucumber," "green-corn," "horse-pond," and the like, are produced by the growth, death, and decay of minute organisms, especially those known as algæ; but, however objectionable these odors and tastes may be from an æsthetic standpoint, it has not been proven that they are productive of disease.

D. D. Jackson has shown * that the odors caused by the undecomposed microscopical organisms are due to compounds of the nature of essential oils; and Whipple points out that the amount of such oil produced by an abundant growth of the organisms is quite sufficient to account for the effect observed.†

He notes, for comparison, that oil of peppermint can be recognized when diluted with water in the proportion of one part of oil to fifty million parts of water; and that when *Asterionella* is present to the extent of fifty thousand organisms per cubic centimetre the dilution of its oil is in the proportion of about one part to two million parts of water.

Whipple further suggests that the flow of water through pipes may cause disintegration of organisms with liberation of the odor producing oil; hence the odor at the tap may be greater than at the intake. May it not be, however, that the "tap" odor is of mixed quality, partly due to products of decomposition?

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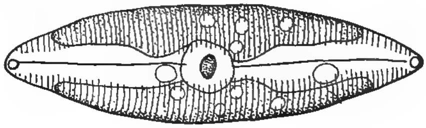
* Tech. Quarterly, x. 419. † Microscopy of Drinking-water, p. 123.

This matter of odor and taste is again considered under "stored water," page 272.

The droplets of oil above referred to are shown in the following "camera lucida" drawing of a diatom. The drawing was made by Mr. W. H. Long.*



Although natural waters are to be found bearing in solution most varied assortments of mineral ingredients, yet such cannot be considered potable, except in the sense that they are medicinal, and they consequently do not find place in the present writing. When those minerals are present, however, which give to the water the characteristic known as "hardness," the case is quite different, for such a property obtains, to a greater or less degree, in every public supply. As to the wholesomeness of such a water, there is widespread opinion that a high degree of hardness is not compatible with safety; but although hard waters do often produce certain intestinal derangements in persons not accustomed to their use, there are no sufficient statistics on record tending to confirm the popular belief that they lead to the formation of urinary calculi. It is a matter of common observation that sudden change from the use of a pure, soft water to one equally pure, but harder, or *vice versa*, results in temporary intestinal derangement, showing the difficulty to be due rather to the change than to the inherent character of the water employed. As has been pointed out by Prof. Drown, the waters of the south of England are exceedingly hard, but the statistics do not show an increase of death-rate resulting therefrom. While considering the

* Bul. Univ. Texas, v. 22.

wholesomeness of hard water, the English Rivers Pollution Commission (Sixth Report) collected the following statistics, the comparison having been made between towns of the same class, in which the general conditions of life are similar. The conclusion was: "Where the chief sanitary conditions prevail with tolerable uniformity, the rate of mortality is practically uninfluenced by the softness or hardness of the water."

TOWNS SUPPLIED WITH SOFT WATER.

Kind of Town.	Number of Towns.	Average Population.	Average Annual Mortality per 1000 Inhabitants.
Seaport	5	162,801	29.4
Inland manufacturing	5	172,860	29.7
Inland non-manufacturing	8	10,751	25.4
Watering-places	5	48,430	19.5

TOWNS SUPPLIED WITH MODERATELY HARD WATER.

Seaport	3	226,172	32.1
Inland manufacturing	8	108,715	26.9
Inland non-manufacturing	4	62,372	26.0
Watering-places	3	33,480	19.2

TOWNS SUPPLIED WITH HARD WATER.

Seaport	6	116,406	25.1
Inland manufacturing	5	144,981	25.5
Inland non-manufacturing	20	29,169	23.2
Watering-places	12	53,170	20.4

In an article on "The Importance of Magnesia in Drinking-water" * Percy Frankland shows that a very great percentage of the population of England are to-day using waters containing from 40 to 60 parts of MgO per million; and that consequently the prejudice existing against magnesian waters,

* International Congress of Hygiene, London, 1891.

on account of their supposed production of calculi, goitre, and cretinism, should not be given undue importance.

In 1889 Professor Kocher investigated the occurrence and distribution of goitre in the canton of Bern, Switzerland, and published an interesting map showing the varying frequency of the disease with change of geological conditions.* He was, moreover, able in a few instances to definitely classify certain local waters as producers or non-producers of goitre. The analyses of two such waters are here given, in parts per million:

	Producing Goitre.	Not producing Goitre.
Specific gravity at 17° C......	1.000316	1.00041
Lime (CaO)................	79.	80.7
Magnesia (MgO)............	5.4	10.9
Calcium sulphate ($CaSO_4$)......	9.01	36.1
Chlorine (Cl)................	4.97	7.
Silica (SiO_2)................	3.3	4.5
Iron and alumina............	traces	traces
Organic matter.............	"	"
Nitrates...................	"	"
Nitrites....................	none	none
Ammonia....................	"	"
Iodine and bromine..........	"	"

It is interesting to note in the above analyses that the magnesia, about which fears have been expressed, is much larger in the non-goitre-producing water than in that which is credited with causing the disease.

Professor Kocher has made cultures of the bacteria occurring in the two classes of water, and has injected rabbits therefrom, with the result that glandular swellings have been produced in several of the animals treated with preparations from the "goitre-water." Nothing definite has, however, been as yet secured. Our present knowledge upon the subject is, therefore, in a very unsatisfactory state, except in so far as

* Vorkommen und Vertheilung des Kropfes im Kanton Bern.

we may be assured that the chemical ingredients of a water cannot be held to be goitre-producing.

Lying between ordinary hard waters and those of a true mineral character is a group, principally of artesian origin, whichc ontains sundry objectionable mineral ingredients, such as magnesium chloride, hydrogen sulphide, and the like, and which would hardly be considered potable did they occur in well-watered regions, but which are thankfully received by people very willing to take almost any water they can obtain.

Turbidity is exceedingly common in the river-waters of this country, particularly in those of the great central basin. The quantity of suspended claylike material present naturally varies in each stream with the conditions of the season, being at times entirely absent in some of them, while with others the existence of more or less muddiness appears to be a constant characteristic.

Ockerson reports that four different surface-samples of Mississippi river-water contained 576, 788, 1030, and 348 parts per million of sediment. On July 2, 1894, the same river-water, at New Orleans, contained 2360 parts per million of solids, mostly silt. Below the junction of the clear Mississippi with the muddy Missouri, the two waters flow on for many miles, side by side, with a distinct line of division.

With reference to the influence of the suspended mineral matter upon health, we find some conflict of opinion. It is an unquestioned fact that very roily water is ingested by many of our communities with no traceable evil results, but the preponderance of testimony goes to show that immunity is attained by continued use, and that the visiting stranger is not upon the same platform of safety with the acclimated native. To quote a typical instance: "In 1868 the right wing of the 92d Highlanders, going up the River Indus, suffered from

diarrhœa from the use of the river-water, which at the time was very muddy. The left wing of the same regiment used water from the same source, but precipitated the suspended matters with alum, and had no diarrhœa. The right wing then adopted the same plan with like success." *

In reply to the claim so often advanced that turbidity is a positive advantage, as tending to remove objectionable material from a sewage-polluted river-water, it should be stated that suitable arrangements for sedimentation must be furnished, otherwise no advantage can be expected from the mere presence of the suspended mineral ingredients. It is a well-known fact that precipitating solids will drag down with them other finely divided substances which, if left to themselves, would require long periods of time for complete sedimentation, and that even soluble salts will often be in part carried down by the same cause, as every student of quantitative analysis knows to his sorrow.

It may readily be conceived that, acting in obedience to this principle, the depositing silt would gather to itself, and carry with it, many germs of disease which, if left to themselves in clear water, would require much longer time to fall; but that there is any advantage to be looked for in using a turbid water without sedimentation, and thereby swallowing turbidity, germs, and all, is scarcely rational.

The following is in illustration of the influence of turbidity in causing a more rapid deposition of bacteria diffused throughout a body of water. The results represent the relative numbers, per cubic centimetre, at the surface of a body of water, and at varying depths in the same, under the condition of clearness and also of material turbidity.

The experiment was conducted with a tall tin vessel, one foot in diameter, and tubulated at intervals of one foot, for

* Parke's "Hygiene," i. 341.

drawing samples. The time of settlement was made two hours; and the numbers of bacteria found per cubic centimetre at the successive depths are stated in terms of the number in the surface sample, that being called one hundred.

	Muddy Water.	Clearer Water.
Surface	100	100
Depth of one foot	134	125
" " two feet	166	142
" " three feet	186	169
" " four feet	266	254

Two hours of settlement were not enough to bring out marked contrast between the waters, although the principle was sustained.

The really serious item of contamination, the one to which the sanitarian's attention is most quickly drawn, is that of sewage introduction, and a consideration of the questions arising upon this topic dwarfs all others into comparative insignificance. Shall a water once polluted with sewage material be again used for human consumption? If there be danger in such use, what is its nature, what is its extent, and are there available means for averting it? These are popular questions of the day with which the sanitarian has to grapple.

It would hardly be wise to take the reader's time with a *résumé* of matters, possessing only historic interest, pertaining to this topic; suffice it to say that, within the very recent past, strong views were entertained concerning the self-purification of streams, and also upon certain features of natural and artificial filtration, which we now believe to have been erroneous. That polluted public water-supplies have caused widespread illness and death is established beyond a peradventure, and, from among the many illustrations that might be cited, the

author offers the following in evidence, some of the data having been collected by himself or within his personal experience:

In the autumn of 1887 the city of Messina, Sicily, was visited by an epidemic of cholera. The plague lasted from September 10th to October 25th, during which time there were some 5000 cases and 2200 deaths. Although for a time the number of daily cases was excessive, running as high as 400, the ordinary number was about 70. The population was stampeded, falling from 71,000 to about 25,000. The government felt that a very possible cause for the rapid spread of the scourge lay in a contaminated drinking-water, and an inquiry, resulting in a development of the following facts, fully confirmed the suspicion: The water as it left the gathering-grounds in the mountains was of excellent quality, but it was conveyed to the city in a conduit entirely open. Those who are familiar with European customs will remember that the washing of soiled clothing is there largely an out-of-door occupation, conducted in the nearest available watercourse. For the benefit of the Messina washerwomen a portion of the public water was deflected, before reaching the town, and turned into neighboring washing-pools of stone. A fair proportion of this deflected water, after having been used for laundry purposes, found its way back into the channel, and continued its course to the city. Further contamination occurred within the town itself, for the reason that the mains of the distributing system were of unglazed tile, badly joined, and were laid in the immediate vicinity of unglazed tile sewers, also very leaky. The sewers were at times found on top of, and parallel with, the water-mains.

Acting upon its conviction as to the cause of the great mortality, the government sent tank-ships to the mainland, filled them with pure "Serino" water, supplied the people therewith, and the daily number of cholera cases immediately fell from seventy to five; or, to quote an expression of the

POLLUTION OF A STREAM BY THE WASHING OF SOILED LINEN THEREIN—GENEVA, SWITZERLAND.

time, "the plague ceased as if by magic." A more efficient distributing system has since been introduced, the open conduit has been replaced by modern pipe, and the city has escaped further visitation by cholera.

From what the author saw, however, it would seem that there is much yet to be done towards bettering the Messina water-supply. Great tanks still exist in the suburban gardens where laundry waste-water is stored for irrigation purposes.

Water from wells in these gardens is taken by the city authorities during periods of scant supply from the regular source, thus permitting certain pollution of the municipal supply.

The influence of the washerwomen in spreading cholera in Messina reminds us that the great epidemic at Cuneo, Italy, in 1884, resulting in 3344 cases, was traced to identically the same source. Infected linen had been washed in a brook communicating with the public water-supply.

In 1890 two violent outbreaks of typhoid fever occurred in the valley of the Tees River.*

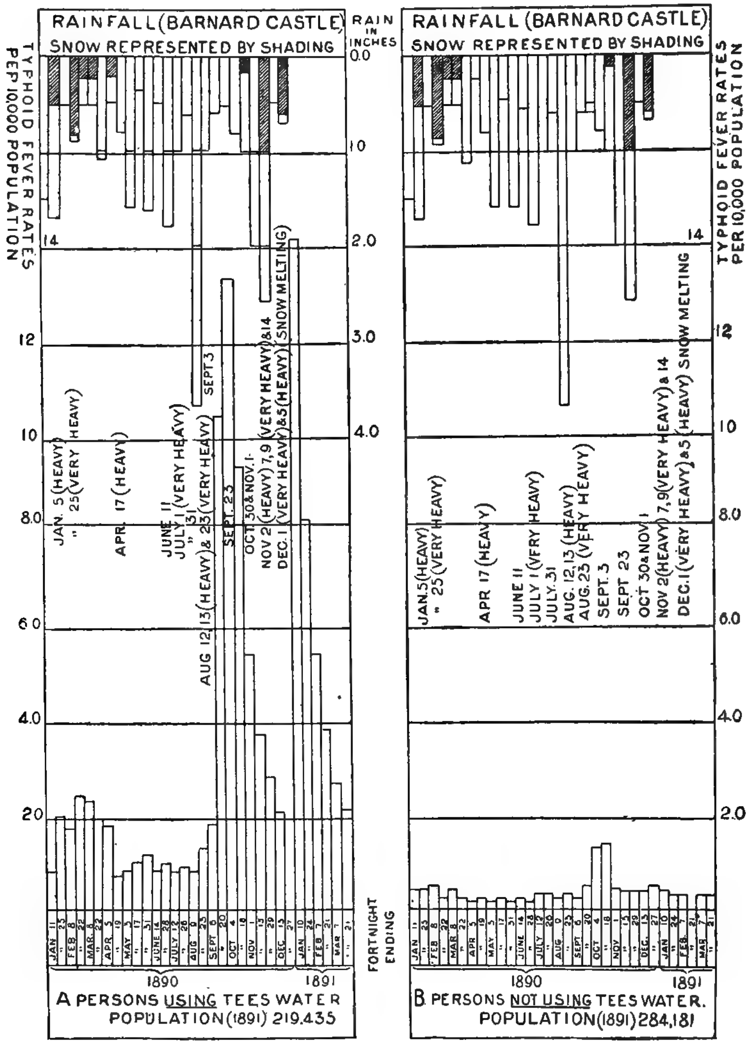
The Tees is a small stream of northern England, about seventy miles long, and navigable for about four miles from its mouth.

Most of the towns of the valley take their water-supplies from the river, but a large scattered population receives water from other sources. The estimated population using Tees water at the time of the outbreak was 219,435, and the number not using such water was 284,181.

In many places, especially in the towns, the river receives all sorts of polluting additions, which are carried on by the current to the intakes below. During dry weather the stream recedes considerably, leaving uncovered its rocky foreshores, which accumulate filth of every variety, and retain the same

* See 21st Report of the London Local Government Board.

until, by reason of heavy rain, the river suddenly rises and sweeps the refuse downward towards the towns nearer the sea.



RAINFALL AND TYPHOID FEVER IN THE TEES VALLEY, ENGLAND.

The result produced upon the thoughtless public, of such an extra and concentrated dose of sewage material added to their water-supply, is best shown graphically by the accom-

panying chart, where it will be observed that increase of rainfall is followed by increase in cases of typhoid fever among the 219,435 persons using the Tees water, after an interval corresponding to the incubation period of the disease, while no appreciable result is noticed among 284,181 people of the same district, using other sources of supply.

The "typhoid rates" given in the chart are "cases," not "deaths."

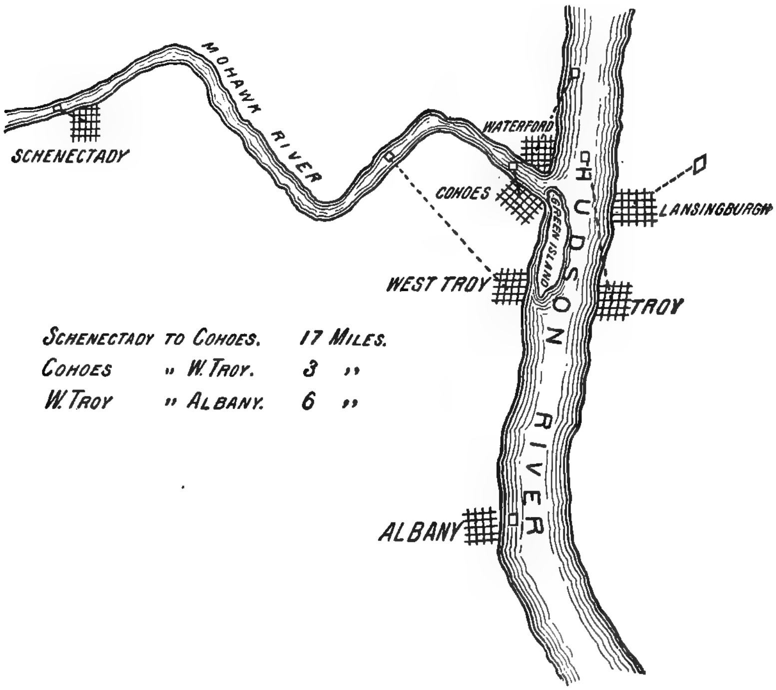
It fell to the author's duty to investigate certain points relating to the typhoid epidemic occurring in the valley of the upper Hudson during the autumn and winter of 1890–91, and the facts secured seem especially instructive.

By a glance at the accompanying chart, the locations will be observed of the several cities and towns situated at and near the junction of the Mohawk and Hudson rivers. Every one of these centres of population drains into the river on whose banks it is situated, and each of them, except Lansingburgh, takes all or the greater portion of its water-supply directly from such river by means of pumps. Mark this difference, however, Waterford and Troy are supplied with Hudson River water above the junction with the Mohawk; Lansingburgh is furnished with water from the hills east of the town, and the village of Green Island obtains its water from wells and a filter-gallery driven into its sandy soil. The others use Mohawk or Mohawk-Hudson water.*

The several intakes are indicated on the chart by squares. Under date of April 11, 1891, the Health Officer of Schenectady wrote the author: "The marked increase in typhoid fever began in July, 1890, and has just let up. We have had about 300 cases. Doctors have not been particular in reporting them, and we have had so many cases of anomalous fevers that diagnosis is questionable. Seventy deaths have been re-

* Albany has since moved its intake up-stream and introduced a modern filtration plant.

ported." Permit me to say that it was not the rule during this epidemic for physicians to do their whole duty in reporting cases. I knew of one instance in which only two or three cases were reported out of twenty-five. Schenectady is a very old town (of 20,000 inhabitants), and its sewerage system is



doubtless none of the best, but its drainage eventually reaches the Mohawk and is carried onward with the current.

The following information was obtained from Dr. Leo, Health Officer of Cohoes, and from Dr. Peltier, his predecessor. Population of Cohoes is 22,000.

The epidemic of typhoid began in Cohoes about the end of October, 1890, and ceased about the middle of the following March. Altogether there were about 1000 cases. The cases were mild in character, resulting in very few deaths. Cohoes

takes its entire water-supply from the Mohawk and returns its sewage into the same river. Boiling of water for drinking purposes was recommended, and no typhoid developed among families who followed the recommendation, except in those instances where members of such families drank unboiled water while at work away from home. A portion of the city is owned by the great Harmony Knitting Mills, and is built up with tenements for their employees, of which there are many hundreds. These tenements are kept in excellent repair and the plumbing is the best in the city, but extends to kitchen sinks and drains only. No water-closets are employed, as each house is furnished with privy vault in back yard. Typhoid was especially bad in this quarter. The Cohoes Health Officer has professional occasion to visit in Waterford (population 5400) and in Lansingburgh (population 10,000), which towns are connected with Cohoes by bridges. He reports that hardly a case existed in either of those towns, and it is to be noted that one of them draws water from the upper Hudson above the Mohawk junction, and the other is supplied from the hills.

West Troy is situated on the Hudson and sewers therein, but by aid of the chart it will be noticed that its water-supply comes from the Mohawk some distance above Cohoes. Its population is 13,000. The following information was obtained from Dr. McNaughton, Health Officer:

"Epidemic typhoid began the last of November. At meeting of Health Board, about December 15th, fifty cases were reported. Of these, forty-two had used Mohawk water, the remainder well-water. On December 20th, the Mohawk supply was shut off and arrangements made with the town of Green Island (which village, by the way, had no fever) to use a portion of its supply. One week thereafter the weekly report of cases showed fifteen, and the second week thereafter but one case was reported. The Green Island supply was used one month. Upon returning to the Mohawk supply in

the middle of January, a slight increase in typhoid was observed. Total number of cases exceeded 100. The fever, as in other places, was very mild, resulting in ten deaths."

Troy is situated directly opposite West Troy. Its population is 65,000. Its water-supply comes partly from lakes back in the hills, and partly from the Hudson above the Mohawk junction.

There were very few cases of typhoid in Troy during the year, and of those few a large percentage were imported from Schenectady and West Troy.

Troy dumps 8,000,000 gallons of sewage into the Hudson daily.

Six miles below Troy is the city of Albany; population, 100,000. Albany, at the time of the epidemic, took its water through an intake in the side of the wharf, directly in front of the city. Not only did sewage from the upper Hudson and Mohawk flow toward it, but during flood tide and south wind the return of its own sewage from the sewer outfalls below had been proven by the floating of buoys.

The typhoid epidemic began in Albany the last of December, 1890. The disease was very mild in character, resulting in sixty-two deaths during the months of January, February, and March, 1891. The total number of typhoid cases reported during the same period was 411, but this figure I have reason to know is unreliable. Albany experienced a very serious epidemic during the winter of 1890–91, and the alarm was widespread, of that there can be no question. A small portion of the city receives its water-supply from an inland gravity source. Typhoid was not nearly so plenty in that section, only eighteen cases having been reported to the end of March.

At Van Wie's point, four miles below Albany, the laborers employed in cutting ice for the great ice-houses had typhoid fever break out among them during January. They used river-water for drinking purposes.

There are those who hold that this outbreak of typhoid fever is to be explained in some other way than by attributing it to a contaminated water-supply, but when we bear in mind that, out of this group of closely situated cities and towns, all of those which used the Mohawk-Hudson water contracted the fever, and that all those which did not use such water escaped, there is much food for thought.

An important case of typhoid outbreak is added to those given, because, though often quoted, and doubtless familiar to most readers, the lesson it teaches is too valuable to risk losing it from the memory. The description is by Dr. E. F. Smith:

"The city of Plymouth, Pa., contains a population of about 8000. In this small community within a period of a few weeks there were more than 1000 cases and 100 deaths from typhoid fever. The epidemic was studied on the spot by competent New York and Pennsylvania physicians, so that no doubt is left either as to the nature of the disease nor as to the method of its introduction and spread.* The facts, sifted and tested by rigid and expert scientific methods, are as follows: The general water-supply of Plymouth is obtained from a mountain brook, a number of dams being thrown across the stream for this purpose. During part of the winter of 1884–5, owing to the deep freezing of this stream, the hydrant water was taken from the neighboring river, Susquehanna. There are very few houses on the banks of the mountain brook, and it would seem that the stream is unusually well protected from sources of contamination. During the time that the stream was frozen a man came from Philadelphia ill of typhoid fever. He had contracted the disease at a place from which three other persons, ill of fever, had been removed to the hospital. This man was cared for in a house near the source of this mountain stream, or at least considerably above where the

* "Report upon the Epidemic of Typhoid Fever at Plymouth, Pa." By Lewis H. Taylor, M.D., of Wilkesbarre, Pa.

city water-supply was procured. The discharges from the bowels of the ill man were not disinfected. They were thrown by the nurse on the deep snow of a side hill sloping toward the stream which was not over forty feet distant. A sudden rise in the temperature toward the close of March caused a general thaw, and the melted snow of the hillside with its mass of typhoid poison was swept into the stream. At just this time, owing to the rise of the water in the brook, the Susquehanna river-water was shut off from the water-mains, and that of the brook turned on again. In this way the typhoid poison was pumped to all parts of the city. In about two or three weeks hundreds of cases of fever developed, and these were confined exclusively to persons who used the hydrant water. No cases were traceable to well-water except much later, and by secondary infection. Whole groups of families using well-water or river-water exclusively escaped entirely. In parts of the city where the use of well-water was the rule and the use of hydrant water the exception only those families suffered which used the latter. One notable instance is mentioned by Dr. Taylor where in the upper end of the city one family only suffered from the disease. It was supposed at first that all in that vicinity used well-water, but further inquiry showed this one family to have been in the habit of catching and using the hydrant water which leaked from the main aqueduct on its way down into the city, preferring the pure water of the mountain stream to that of the foul wells of the neighborhood. Such cases are, of course, no argument in favor of a return to the use of well-water, but only one for greater care to prevent accidental contamination. This outbreak speaks volumes in favor of the specific nature of the typhoid-fever poison."

The cost of this outbreak, in actual cash, is fortunately well established, and is deserving of attention by those charged with the care of the public health. It is itemized as follows:

Loss of wages for those who recovered..	$30,020.08
Care of the sick..	67,100.17
Yearly earnings of those who died.....	18,419.52

Very similar to the Plymouth outbreak was that at New Haven during the first part of 1901. Up to April there had been 315 cases reported.

"In the remote limits of an adjoining town, eight miles from New Haven, there had been during the first three months of the year, at different times, three cases of typhoid. The discharges from the patients were not disinfected.

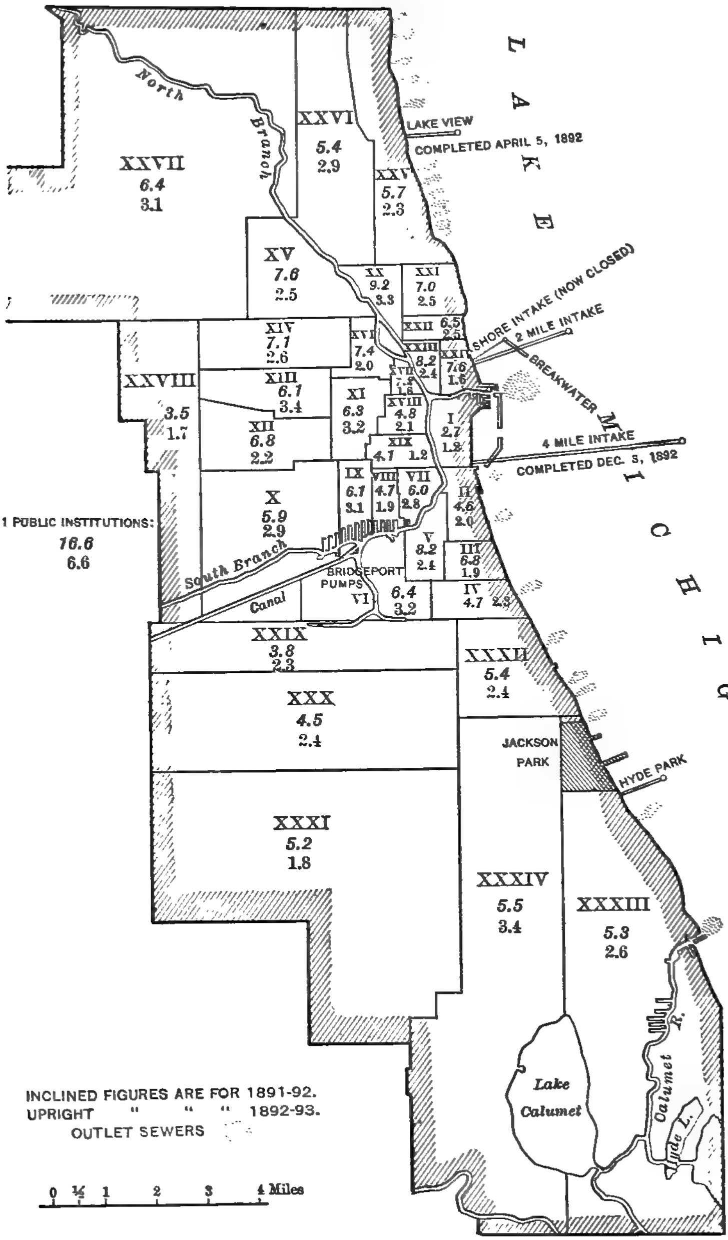
"During the illness of these patients the ground was frozen solid, and there is every reason to believe that there was no true burial of the feces. The alleged place of burial was on a side hill with a steep inclination to a watercourse leading directly to Dawson Lake, an important reservoir of the New Haven Water Company."

When it is remembered that much of the Chicago sewage flows into Lake Michigan, and that until recently the intakes supplying the city with the lake-water were situated only a few hundred feet off shore, a comparison of the typhoid death-rates before and after the driving of the four-mile tunnel is suggestive. The tunnel was opened December 3d, 1892.

	Year ending Sept. 30, 1892.	Year ending Sept. 30, 1893.
Deaths in Chicago from typhoid fever......	1790	712
Per cent of typhoid deaths to total deaths..	6.72	2.64

This is better seen, and in more detail, by consulting the map on page 40, kindly furnished by the *Engineering News*.

Much as the new tunnel did for Chicago, the difficulty was not entirely remedied, for the reason that sewage occasionally reached the four-mile crib, as is shown by the following abstract and the ward map (page 43) published by the Chicago *Tribune* of Sept. 28, 1895:



MAP OF CHICAGO SHOWING BY WARDS THE PERCENTAGES OF DEATHS FROM TYPHOID FEVER TO TOTAL MORTALITY AND THE WATER-WORKS INTAKES AND SEWER OUTLETS FOR THE YEARS ENDING SEPT. 30, 1892, AND SEPT. 30, 1893.

"Typhoid fever is epidemic in Lake View. While the spread and prevalence of the disease are not so great in Hyde Park and the Town of Lake, still conditions in these two sections of the city are so severe as to cause alarm.

"The whole trouble rests with the impure water-supply. North of the tunnel five sewers empty into the lake, and just south of it there are eight more. The disease is only normal in the area south of Chicago Avenue and Thirty-ninth Street. All of the West Side is particularly free. This is because the district between Chicago Avenue and Thirty-ninth Street is supplied with water through tunnels from intake cribs two and four miles out in the lake."

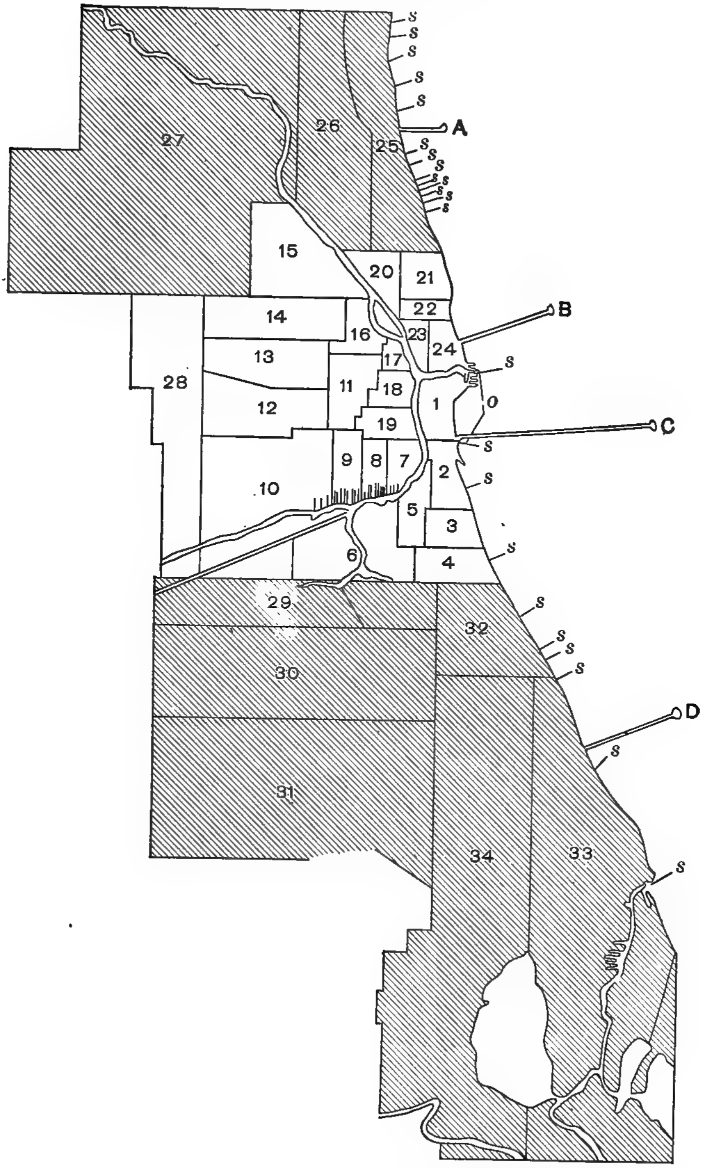
The following table, compiled by Mr. John W. Hill, shows very clearly the influence of proper methods of water-purification upon the death-rate from typhoid fever:

City.	Average Typhoid Mortality, 1890–1894, per 100,000.	Water-supply.
The Hague	4.9	Filtered from sand dunes.
Rotterdam	5.2	Filtered from river Maas.
Christiania	6.8	
Dresden	6.9	Filter-gallery, River Elbe.
Vienna	7.	Springs in the Schneeburg.
Munich	7.1	Springs, Mangfall Valley.
Copenhagen	7.9	
Berlin	8.	Filtered, Lake Tegel and River Spree.
Breslau	11.6	Filtered from River Oder.
Amsterdam	13.9	Filtered from Haarlaem Dunes.
Stockholm	14.3	
Brisbane	14.3	
London	14.6	Kent Wells, filtered from Thames and Lea.
Edinburgh	15.8	Filtered from Reservoir in Pentland Hills.
Trieste	17.	
Brooklyn	19.	Impounded and wells.
New York	20.4	Impounded from Croton and Bronx rivers.
Davenport, Ia.	21.4 (1895—26)	Mechanical filtration from Mississippi.
New Orleans	21.4	Rain-water from tanks and cisterns.
Sydney	21.6	Impounded from Upper Nepeau.
Hamburg	21.8 (1895—6)	River Elbe (filtered since May, 1893.)
Budapest	22.4	Ground-water from wells.
Glasgow	22.8	Lake Katrine.
Brussels	26.2	
Paris	26.4	River Seine, Marne, Vanne, and Ourcq Canal, wells, etc.
Manchester	27.6	Lake Thirlmere.
Venice	30.2	

City.	Average Typhoid Mortality, 1890–1894, per 100,000.	Water-supply.
Milwaukee	32.	Lake Michigan.
Rome..........	32.2	Fontanadi Trevi, Acqua Felice and Paoli.
Boston	32.6	Lake Cochituate and Sudbury River.
Detroit........	33.8	Detroit River.
Dayton........	36.	Driven wells.
Turin..........	36.8	
Liverpool......	37.	Lake Vyrnwy.
Buffalo........	39.2	Niagara River.
Providence....	39.2	Pawtuxet River.
Covington.....	39.4	Ohio River.
San Francisco..	40.2	
Prague........	43.2	
Minneapolis....	45.4	Mississippi River.
Baltimore......	45.8	Lake Roland and Gunpowder River.
Newark........	45.8	Impounded from Pequannock River since [April, 1892.
St. Louis	47.	Mississippi River.
Newport, Ky ..	47.5	Ohio River.
Philadelphia...	48.2	Delaware and Schuylkill rivers.
Denver........	48.3	South Platte River.
Cleveland......	49.2	Lake Erie.
St. Petersburg.	52.3	Filtered from River Neva.
Cincinnati.....	52.4	Ohio River.
Moscow........	57.	Springs, ponds, Moscow and Yanzi rivers.
Toronto.......	57.8	Lake Ontario.
Quincey, Ill....	58.	Mechanical filtration from the Mississippi [River.
Dublin........	58.8	Filtered from river Vartry.
Knoxville......	61.9 (1895—59)	Mechanical filtration from Tennessee [River.
Milan..........	62.	
Jersey City....	75.	Passaic River.
Washington....	76.6	Potomac River.
Louisville......	79.4	Ohio River.
Chattanooga...	80. (1895—48)	Tennessee River.
Chicago.......	84.	Lake Michigan.
Pittsburg......	91.7	Allegheny River.
Lowell	92.4	Driven wells and Merrimac River.
Atlanta........	92.8 (1895—43)	Mechanical filtration from Chattahootchee River.
Lawrence......	96.2 (1895—48)	Natural filtration from Merrimac River [since 1893.
Alexandria	162.4	Nile.
Cairo..........	189.4	Nile.

The average typhoid death-rate, per 100,000, in 1895, for the thirty-three largest cities of Great Britain, was 20.

The table on page 44, compiled by G. W. Fuller, is worthy of study. The Cochituate water-supply was introduced into Boston in 1848, and, since its introduction, very much has been done to increase its purity. The change for the better is marked, judging from the death-rate.



MAP SHOWING TYPHOID-FEVER DISTRICTS.

S, sewers emptying into the lake; *A*, Lake View one-mile crib; *B* and *C*, two- and four-mile cribs supplying district not infected; *D*, one- and two-mile Hyde Park and Town of Lake crib. Shaded wards are where the disease was epidemic.

TABLE SHOWING DEATH-RATES FROM TYPHOID FEVER IN BOSTON, 1846–1892.

Years.	Deaths per 100,000 Inhabitants.
1846–49	174
1850–54	82
1855–59	50
1860–64	57
1865–69	56
1870–74	76
1875–79	42
1880–84	49
1885–89	41
1890–95	31
1896–99	32

In the State of Connecticut the typhoid statistics for the past forty-three years show a continual improvement, which must be due, at least in part, to abolition of old private wells for new and better water-supply. The percentage of deaths (for the entire State) from typhoid to total deaths from known causes stands as follows:

Average for the five years	1855–60	4.99 per cent.
" " " " "	1860–65	5.86 " "
" " " " "	1865–70	5.80 " "
" " " " "	1870–75	4.69 " "
" " " " "	1875–80	2.77 " "
" " " " "	1880–85	2.25 " "
" " " " "	1885–90	2.21 " "
" " " " "	1890–95	1.91 " "
" " " " "	1896–98	1.26 " "

Statistics compiled for the Massachusetts Board of Health by Mr. H. F. Mills * show how greatly the typhoid death-rate

* Mass. Board of Health, 1890.

is improved in towns by a change from the domestic well system to that of a public supply.

CHANGE IN THE DEATH-RATE FROM TYPHOID FEVER PER 100,000 INHABITANTS IN CITIES OF MASSACHUSETTS WHICH INTRODUCED WATER-SUPPLIES FROM 1867 TO 1876.

	Annual Average, 1859-68.	Date of Water-supply.	Annual Average. 1878-89.	Per Cent. of Average.
Fall River	77.8	1874	63.2	81
Springfield	96.7	1875	52.9	55
Taunton	61.2	1876	50.2	82
Northampton	109.8	1871	40.4	37
Lynn	90.6	1871	38.7	43
New Bedford	77.7	1869	38.0	49
Newton	65.7	1876	36.5	56
Malden	80.4	1870	35.4	44
Fitchburg	105.9	1872	31.6	30
Woburn	82.9	1873	29.5	36
Somerville	42.8	1867	29.5	69
Chelsea	59.7	1867	28.9	48
Waltham	81.2	1873	24.2	30
Average	79.4		38.3	

For the entire State of Massachusetts the rates are as follows:

Year.	Total Deaths from Typhoid.	Rate per 100,000 Population.	Percentage of Typhoid Deaths to Total Deaths.
1873	1406	89	4.15
1874	1147	71	3.6
1875	1059	64	3.02
1876	881	53	2.65
1877	814	48	2.59
1878	679	39	2.16
1879	637	36	2.00
1880	882	49	2.50
1881	1072	59	2.94
1882	1079	58	2.93
1883	860	46	2.28
1884	875	46	2.36
1885	768	39	2.02
1886	800	40	2.15
1887	922	45	2.26
1888	943	45	2.24
1889	891	41	2.13
1890	835	37	1.92
1891	821	36	1.82
1892	827	35	1.69

This is a showing which is very encouraging, and which effectually answers the frequently recurring question, "How was it our fathers got along so well without all these so-called modern improvements?"

Figures such as the above, and others like them that might be quoted, stand in evidence that the question is a begged one, and that our progenitors were not so well off as many people fancy.

In illustration of just this point, it is instructive to note the statistics given for the total death-rate of London, by Dr. Lyon Playfair, at the Social Science Congress held at Glasgow in 1874:

Period.	Death-rate per 1000.
1660–79	80.0
1681–90	42.1
1746–55	35.5
1846–55	24.9
1871	22.6

The same statistics, but more extended, are given graphically in the report of the State Board of Health of Michigan, and are given on page 48.

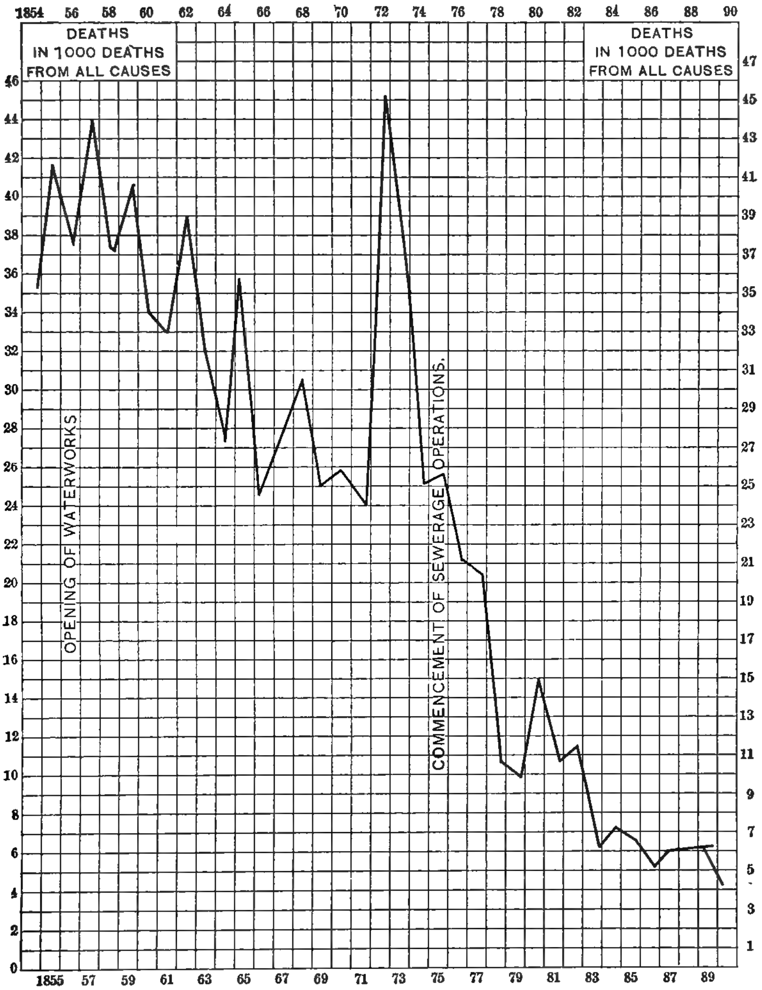
In this connection it is interesting to observe the increase in the median age of the population of the United States: *

1850	18.28 years
1860	18.87 "
1870	19.65 "
1880	20.45 "
1890	21.38 "
1900	22.3 (estimated)

It might be well to note that water-supply systems should not be introduced into country towns until arrangements have

* Merriman's "Sanitary Engineering" (1899), page 43.

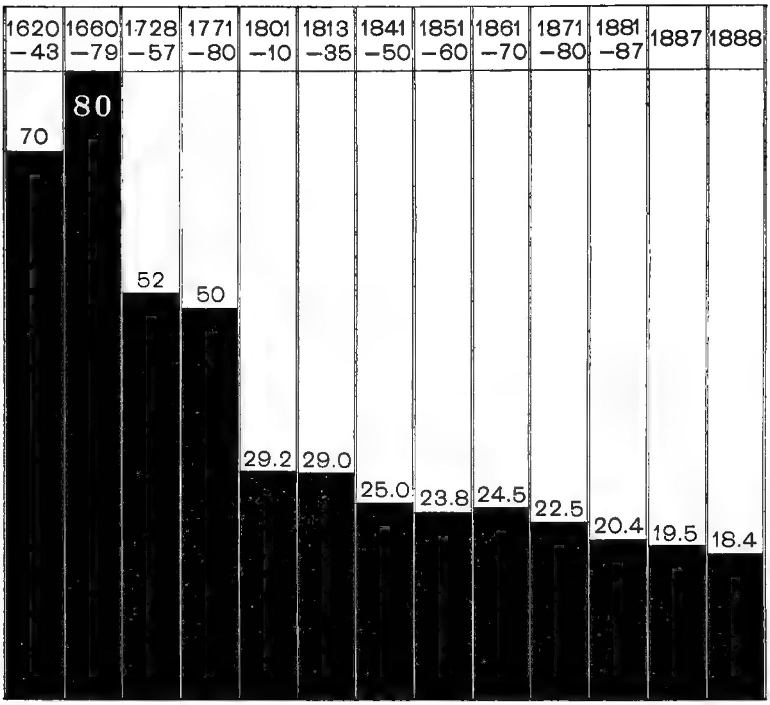
been made to care for the necessarily increased amount of sewage thereby produced; otherwise the old vaults may



TYPHOID MORTALITY IN BERLIN (ROECHLING).

become overloaded and carry pollution to greater distances than it went before, thus damaging the remaining wells.

As showing the exceeding difference between care and no care in the selection of water for potable supply, the following



DEATHS IN LONDON FROM ALL CAUSES PER 1000 POPULATION PER ANNUM IN PERIODS REPRESENTING THE 17TH, 18TH, AND 19TH CENTURIES.

quotation is taken from a report by Dr. Simmons, of the Yokohama Board of Health, covering certain features of the water question in India:

"The drinking-water supply is derived from wells, so-called 'tanks' or artificial ponds, and the watercourses of the country. The wells generally resemble those in other parts of Asia. The tanks are excavations made for the purpose of collecting the surface-water during the rainy season and storing it up for the dry. Necessarily they are mere stagnant pools. The water is used not only to quench thirst, but is said to be drunk as a sacred duty. At the same time, the reservoir serves as a large washing-tub for clothes, no matter how dirty or in what soiled condition, and for personal

bathing. Many of the watercourses are sacred; notably the Ganges, a river 1600 miles long, in whose waters it is the religious duty for millions, not only for those living near its banks, but of pilgrims, to bathe and to cast their dead. The Hindoo cannot be made to use a latrine. In the cities he digs a hole in his habitation; in the country he seeks the fields, the hillsides, the banks of streams and rivers when obliged to obey the calls of nature. Hence it is that the vicinity of towns and the banks of the tanks and watercourses are reeking with filth of the worst description, which is of necessity washed into the public water-supply with every rainfall. Add to this the misery of pilgrims, their poverty and disease, and their terrible crowding into the numerous towns which contain some temple or shrine, the object of their devotion, and we can see how India has become and remains the hot-bed of the cholera epidemic. In the United States official report, the horrors incident upon the pilgrimages are detailed with appalling minuteness. W. W. Hunter, in his Orissa, states that twenty-four high festivals take place annually at Juggernaut. At one of them, about Easter, 40,000 persons indulge in hemp and hasheesh to a shocking degree. For weeks before the car festival in June and July, pilgrims come trooping in by thousands every day. They are fed by the temple cooks to the number of 90,000. Over 100,000 men and women, many of them unaccustomed to work or exposure, tug and strain at the car until they drop exhausted and block the road with their bodies. During every month of the year a stream of devotees flows along the great Orissa road from Calcutta, and every village for three hundred miles has its pilgrim encampments. The people travel in small bands, which at the time of the great feasts actually touch each other. Five sixths of the whole are females, and ninety-five per cent travel on foot, many of them marching hundreds and even thousands of miles, a contingent having been drummed up from every town or

village in India by one or other of the three thousand emissaries of the temple, who scour the country in all directions in search of dupes. When those pilgrims who have not died on the road arrive at their journey's end, emaciated, with feet bound up in rags and plastered with mud and dirt, they rush into the sacred tanks or the sea, and emerge to dress in clean garments. Disease and death make havoc with them during their stay; corpses are buried in holes scooped in the sand, and the hillocks are covered with bones and skulls washed from their shallow graves by the tropical rains. The temple kitchen has the monopoly of cooking for the multitude, and provides food which, if fresh, is not unwholesome. Unhappily, it is presented before Juggernaut, so becoming too sacred for the minutest portion to be thrown away. Under the influence of the heat it soon undergoes putrefactive fermentation, and in forty-eight hours much of it is a loathsome mass, unfit for human food. Yet it forms the chief sustenance of the pilgrims, and is the sole nourishment of thousands of beggars. Some one eats it to the very last grain. Injurious to the robust, it is deadly to the weak and wayworn, at least half of whom reach the place of suffering under some form of bowel complaint. Badly as they are fed, the poor wretches are worse lodged. Those who have the temporary shelter of four walls are housed in hovels built upon mud platforms about four feet high, in the centre of each of which is the hole which receives the ordure of the household, and around which the inmates eat and sleep. The platforms are covered with small cells without any windows or other apertures for ventilation, and in these caves the pilgrims are packed, in a country where, during seven months out of the twelve, the thermometer marks from 85° to 100° Fahr. Hunter says that the scenes of agony and suffocation enacted in these hideous dens baffle description. In some of the best of them, 13 feet long by 10 feet broad and 6½ high, as many as 80 persons pass the night. It is not,

then, surprising to learn that the stench is overpowering and the heat like that of an oven. Of 300,000 who visit Juggernaut in one season, 90,000 are often packed together for a week in 5000 of these lodgings. In certain seasons, however, the devotees can and do sleep in the open air, camping out in regiments and battalions, covered only with the same meagre cotton garment that clothes them by day. The heavy dews are unhealthy enough; but the great festival falls at the beginning of the rains, when the water tumbles in solid sheets. Then lanes and alleys are converted into torrents or stinking canals, and the pilgrims are driven into the vile tenements. Cholera invariably breaks out. Living and dead are huddled together. In the numerous so-called corpse-fields around the town as many as forty or fifty bodies are seen at a time, and vultures sit and dogs lounge lazily about gorged with human flesh. In fact, there is no end to the recurrence of incidents of misery and humiliation, the horrors of which, says the Bishop of Calcutta, are unutterable, but which are eclipsed by those of the return journey. Plundered by priests, fleeced by landlords, the surviving victims reel homeward, staggering under their burdens of putrid food wrapped up in dirty clothes, or packed in heavy baskets or earthenware jars. Every stream is flooded, and the travellers have often to sit for days in the rain on the bank of a river before a boat will venture to cross. At all these points the corpses lie thickly strewn around (an English traveller counted forty close to one ferry), which accounts for the prevalence of cholera on the banks of brooks, streams, and rivers. Some poor creatures drop and die by the way; others crowd into the villages and halting-places on the road, where those who gain admittance cram the lodging-places to overflowing, and thousands pass the night in the streets, and find no cover from the drenching storms. Groups are huddled under the trees; long lines are stretched among the carts and bullocks on the roadside, their hair

saturated with the mud on which they lie; hundreds sit on the wet grass, not daring to lie down, and rocking themselves to a monotonous chant through the long hours of the dreary night. It is impossible to compute the slaughter of this one pilgrimage. Bishop Wilson estimates it at not less than 50,000. And this description might be used for all the great Indian pilgrimages, of which there are probably a dozen annually, to say nothing of the hundreds of smaller shrines scattered through the peninsula, each of which attracts its minor hordes of credulous votaries. So that cholera has abundant opportunities for spreading over the whole of Hindostan every year by many huge armies of filthy pilgrims; and the country itself well deserves the reputation it universally possesses of being the birthplace and settled home of the malady."

With the Chinese it is quite different. "Although their country is in closest proximity to India, and of much greater extent and twice as populous, you will find that cholera is comparatively rare. The drinking-water supply of China is derived from wells, springs, and natural streams. Now, though the wells and springs are used in China for drinking purposes to much the same extent and in much the same manner as in India, yet the rivers and lakes are not drunk from as a part of a religious duty, nor is bathing in them a sacred rite. The absence of pilgrimages contributes to keep the water comparatively uncontaminated.

"Human manure is valuable and hoarded for fertilizing purposes. Hence the excreta are deposited by the individual in a receptacle made for the express purpose, and from motives of economy kept in a fairly good condition of repair. Even in cities and large towns latrines are not employed. Special wooden boxes are among the first necessities of bedroom furniture, and form part of every bridal outfit. The contents are daily emptied into earthen jars or wooden tubs placed in

the court-yard of the house, whence they are removed by the scavenger either direct to the fields, or to boats destined to convey them to a distance. Thus the greatest amount of security attainable is provided against the contamination of the water-supply from this source. A still more potent preventive of infection is to be found in the fact that the Chinese will always, if possible, boil water before drinking it, even if they are unable to make it into some kind of tea. Here it is easy to see, in the contrast between the customs of the Hindoo on the one hand and the Chinese on the other, how in the one case every possible facility is provided for the propagation of infection; in the other, how the danger of contamination is reduced to a minimum."

This statement concerning China is hardly in accord with the following naval report:

"In Japan and China the close relation of the food and water supply with the excreta not only illustrates the ætiology of cholera, but, at the same time, shows what small prospect there is of its extermination. In Japan the soil is tilled in absolute contiguity to the wells, and is fertilized with liquefied human excreta. Dr. Jameson, a physician of Shanghai, cites an instance where, under a spigot, he saw the rice for the daily food being washed at the same time with a vessel just emptied of cholera discharges." *

Illustrations such as have been given, showing the power of water to carry specific disease, could be very greatly multiplied. J. W. Hill has published a list of cases of this character in *J. Am. Water-works Asso.*, 1897, 168; Wilson's "Handbook of Hygiene" furnishes a further number, notably the celebrated "Broad Street well case"; the widely known report of the epidemic at Lausen, Switzerland, will be found in *Nature*, xiii. 447; while a historic summary of two hundred

* Report of Surgeon-General U. S. Navy, 1892.

and five outbreaks of "water-borne typhoid" in Great Britain has been published by E. Hart in a report prepared for the Parliamentary Bills Committee of the British Medical Association, 1897. It would not be wise to devote space to these cases beyond the references given, but it is well to pause for a moment to consider what may be learned from the terrible outbreak of cholera at Hamburg, Germany, in 1892.

The city had at that time a population of 640,400. In the official tabulation the epidemic is noted as having lasted from August 16th to November 12th, although 42 deaths appear to have taken place in the next month (December) and 20 in January, 1893. The total number of cholera cases reported during that time was 17,020, with a total death-list of 8605, a mortality percentage of 50.05.

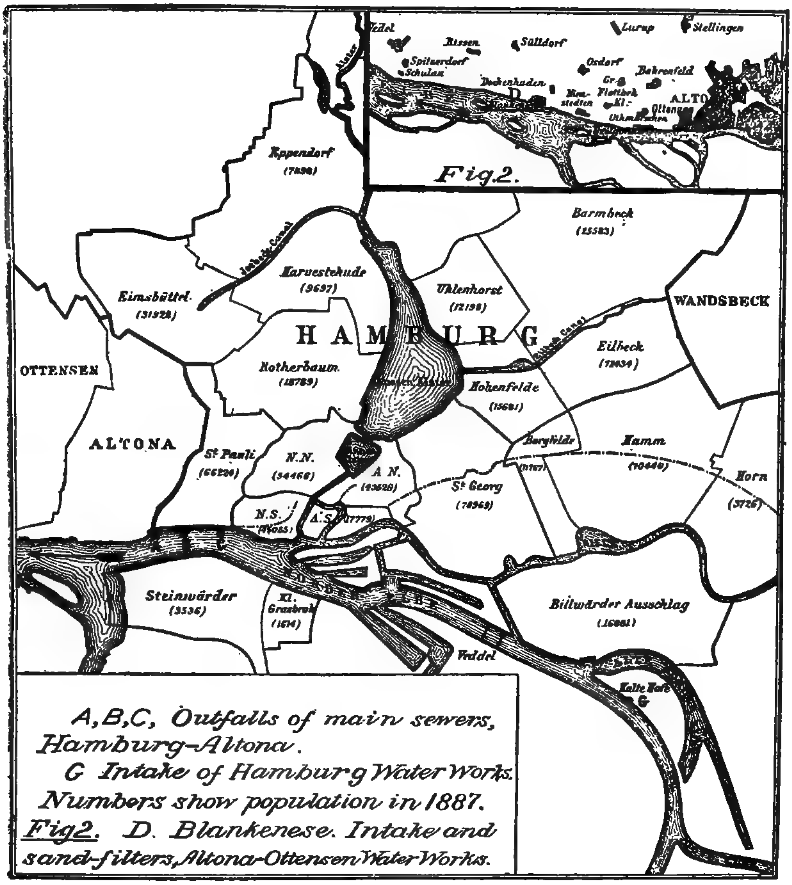
By months the cases were:

August	7,427
September	9,341
October	181
November	7
December	42
January	20
February	1
March	1
	17,020

To a proper appreciation of the conditions of this epidemic a study of the local map is essential.

It will be observed that Altona (143,000 population), Hamburg (640,400 population), and Wandsbeck (20,000 population) are practically one and the same town, separated by only imaginary boundaries, which a stranger could not locate. The three municipalities are, however, supplied with water from three different sources. Wandsbeck obtains filtered water from a lake unexposed to contamination; Hamburg

pumps water from the Elbe River, and in 1892 the intake was situated just south of the city, but not far enough up-stream to escape contamination from a recession of polluted water at flood-tide. After some imperfect sedimentation, the water



AFTER REINKE AND SEDGWICK.

passed directly to the consumer without filtration. Altona, strangely enough, pumps its water from the Elbe at a point about eight miles below that at which the river receives the combined sewage of the three cities, with their population of over 800,000. Fortunately for Altona, this most grossly

polluted supply is filtered with exceeding care before delivery to the people. Further description of the Hamburg epidemic can best be given in the words of Dr. Thorne, medical officer of the London Local Government Board: *

"The different behavior of Hamburg and Altona as regards cholera is extremely interesting in this connection. The two towns adjoin; they are practically one city. The division between the two is no more obvious than that between two densely peopled London parishes, and yet a spot-map indicating the houses which were attacked with cholera, which was shown to me by Professor Koch, points out clearly that whereas the disease prevailed in epidemic form on the Hamburg side of the boundary line, that line, running in and out among the streets and houses and at times passing diagonally through the houses themselves, formed the limit beyond which the epidemic as such did not extend. The dots on one side of the dividing line were proof of the epidemicity of cholera in Hamburg; their comparative absence on the Altona side of it was proof of the absence of an epidemic in Altona. To use Professor Koch's own words: 'Cholera in Hamburg went right up to the boundary of Altona and there stopped. In one street, which for a long way forms the boundary, there was cholera on the Hamburg side, whereas the Altona side was free from it.' And yet there was one detectable difference, and one only, between the two adjacent areas—they had different water-services.

"Professor Koch has collected certain proofs which he regards as crucial on this point, and Dr. Reincke has supplied me with a small plan in support of the contention. At one point close to and on the Hamburg side of the boundary line between Hamburg and Altona is a large yard known as the Hamburger-Platz. It contains two rows of large and lofty

* "Cholera Prospects and Prevention," London, 1893.

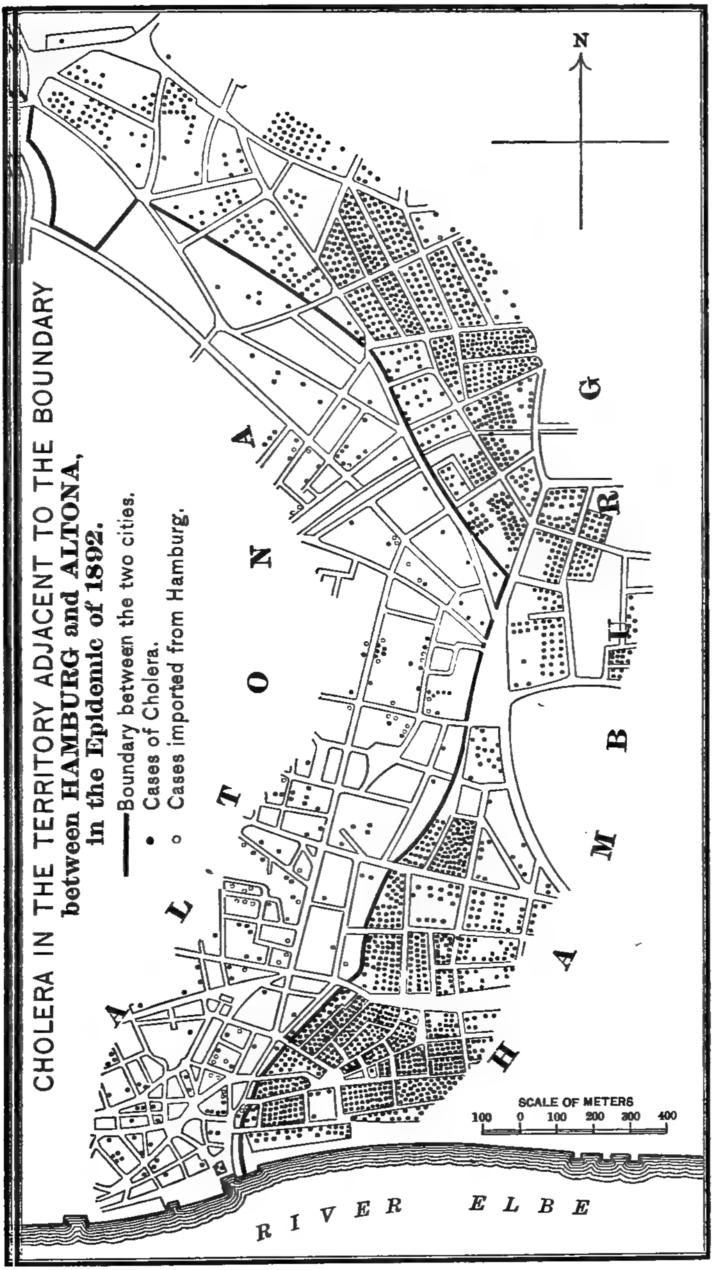


CHART SHOWING DISTRIBUTION OF CHOLERA CASES IN THE EPIDEMIC OF 1892.
(From "Filtration of Municipal Water-supply," by Rudolph Hering.)

dwellings, containing seventy-two separate tenements and some 400 people, belonging almost wholly to those classes who suffered most from cholera elsewhere in Hamburg. But whilst cholera is shown by the spot-map to have prevailed all around, not a single case occurred amongst the many residents of this court during the whole epidemic. And why? Professor Koch explains that owing to local difficulties water from the Hamburg mains could not easily be obtained for the dwellings in question, and hence a supply had been laid on from one of the Altona mains in an adjacent street. This was the only part of Hamburg which received Altona water, and I am informed that it was the only spot in Hamburg in which was aggregated a population of the class in question which escaped the cholera. At the date of my visit to Hamburg a notice-board was affixed at the entrance of this court. It stated that certain tenements were to let; but above all, in large type, and as an inducement to intending tenants, was the announcement that the court was not only within the jurisdiction of Hamburg, with the privileges still attaching to the old Hanseatic cities, but that it had a supply of Altona water."

During this epidemic the deaths in the several cities were:

	Population.	Deaths.	Deaths per 10,000 Inhabitants.
Hamburg................	640,400	8605	134.4
Altona..................	143,000	328	23.0
Wandsbeck...............	20,000	43	22.0

"That infectious matter was communicated to the Elbe water from Hamburg is not in any way a hypothesis. Cholera germs had been as a fact found in the Elbe water. They were found a little below the place where the Hamburg main sewer flows into the Elbe. They were also found in one of the two (Altona) basins into which the water flowed before filtration." *

* Koch, *Zeit. für Hygiene und Infect.-Krank.*, xiv.

The following analysis of the Hamburg public supply from the Elbe River, during the cholera epidemic of 1892, is given in *Chemical News*, lxvi. 144:

Appearance	Turbid and very yellow
Taste	Slightly unpleasant
Odor	Extremely small
Deposit	Small and dirty-looking
Chlorine	472.000 per million
Free ammonia	1.065 " "
Albuminoid ammonia	0.293 " "
Nitrates	26.430 " "
Required oxygen (15 minutes)	0.928 " "
" " (4 hours)	3.428 " "
Total solids	1160.700 " "

Dr. Reincke says* in regard to Hamburg that the evidence that the reduction of typhoid in the city has been the result of an improvement in the water is substantiated by the fact that the typhoid among the shipping interests in the harbor, which use the raw water, is as great as it was before, while in the city it has fallen from 90 per 100,000 in 1887 to 6 in 1894 and 9 in 1895. In another place he argues that typhoid fever has always come through the same channels as cholera, and shows by a tabular statement that the maximum of typhoid has followed two or three weeks later than the maximum of cholera, the difference in time representing the longer incubation period of the former disease.

No invasion of cholera has as yet appeared to test the efficiency of the elaborate filter-plant which Hamburg has lately constructed, but the filters are certainly doing good work towards the suppression of typhoid fever.

* "Zur Epidemiologie des Typhus in Hamburg und Altona," paper before the Hamburg Artz, Verein, Jan. 2, 1896; also Fuertes, "Water and Public Health."

To the sanitarian or engineer, who purposes dealing with the question of public water-supply, some knowledge of the ætiology of the two prominent water-borne diseases, "cholera" and "typhoid fever," is essential to the proper and successful meeting of his professional responsibilities.

The cholera "germ" (*spirillum choleræ Asiaticæ*), or "comma bacillus," was discovered by Koch in 1884 in the excreta of cholera patients and in the intestinal contents of those dead of the disease.

The spirillum will grow in ordinary culture-jelly at the usual room temperature, forming in twenty-four hours small white colonies which increase in size and finally entirely liquefy the gelatine. Growth is arrested if the temperature exceed 107° F., or if it fall below 59° F.

In shape it is not unlike the "comma" whence it derives its name, and the union of two or more attached end to end often causes the appearance of semicircles, S-shaped figures, and long spiral filaments. In size the "germ" varies from 0.8 to 2 microns in length, and from 0.3 to 0.4 in breadth. It is generally conceded that the cholera spirillum does not form spores, a characteristic which permits of its ready destruction by heat, a "spore" being much more difficult to destroy than a full-grown bacterium. Sternberg found the thermal death-point to be 52° C. (125.6° F.), the time of exposure having been four minutes, and, although a slightly higher figure has been recorded, by other investigators, there is no question but that the degree of heat required is very low.

"In a moist condition this spirillum retains its vitality for months. Koch found in his early investigations that rapid multiplication may occur upon the surface of moist linen, and also demonstrated its presence in the foul water of a tank in India which was used by the natives for drinking purposes. It is quickly destroyed by desiccation, as first determined by Koch, who found that it did not grow after two or three hours,

when dried in a thin film on a glass cover." If the thickness of the film be considerable, or if the drying take place on silk threads, the vitality may remain for some weeks. (Kitasato.)

VIABILITY OF THE CHOLERA SPIRILLUM IN WATER.

Babes (1884–85) found the organisms alive after seven days in Seine water.

Wolffhügel (1886) found that the germ may live fifteen to twenty days in unsterilized tap-water. He repeatedly found it alive after three months, and believes this due to what has been termed acclimatization. Rarely the organisms die in the first few days. After five to seven days they are many times more numerous than in the primary inoculation.

Karliniski (1889) found the organism dead after two or three days in unsterilized spring-water.

Hockstetter (1887) found that the organism lives indefinitely in unsterilized tap-water even when the water contains large numbers of other organisms. He found the germs alive after an interval of 392 days.

Nicati and Rietsch (1885) found the spirillum alive in sterilized distilled water after twenty days; in sterilized water from the port of Marseilles after eighty-one days; in Marseilles canal-water, thirty-eight days; in sea-water, sixty-four days; in bilge-water from an iron steamship *en route* from Japan, thirty-two days.

Stoddart finds that there is no antagonism between the cholera spirillum and ordinary water organisms. He has kept it alive for weeks in both pure and polluted waters.

According to Kitasato the germs of typhoid and cholera are more hardy than bacteria of putrefaction. On the other hand, Esmarch found that pathogenic germs in dead bodies were quickly killed by putrefactive bacteria. According to Giaxa, cholera germs quickly died in water containing many

other bacteria, and typhoid germs also died, but less quickly. Schiller found that cholera germs lived 14 days in a mixture of excrement and urine, and for 13 days in Berlin sewage. Cunningham found cholera germs lived 4 to 5 days in clear water at room temperature, and in dirty water 4 to 9 days. In the latter water, previously boiled, the germs lived 25 days; in garden earth, 10 to 26 days; in same earth mixed with fæcal material, 6 to 9 days; in same mixture of earth and fæcal matter previously cooked—i.e., sterilized—47 days.

Gruber and von Kerner show the power of the cholera germ to remain alive in river-water, and in that of the Vienna city supply, for seven days.

Sternberg believes that increase of either the cholera spirillum or the typhoid bacillus in ordinary water is unlikely to occur, owing to the interfering action of the common water bacilli.

According to Boer and Bolton the cholera spirillum is killed by a two-hours' exposure to the following solutions: hydrochloric acid, 1 : 1350; sulphuric acid, 1 : 1300; caustic soda, 1 : 150; ammonia 1 : 350; mercuric cyanide, 1 : 60,000; silver nitrate, 1 : 4000; arsenite of soda, 1 : 400; malachite green, 1 : 5000; methyl violet, 1 : 1000; carbolic acid, 1 : 400; mercuric chloride, 1 : 10,000; blue vitriol, 1 : 500.

"Experiment has shown the spirillum to be very sensitive to the action of acids. Stutzer states that a solution of .05 per cent of sulphuric acid is fatal to the cholera spirillum in fifteen minutes, and a .02 per cent solution kills in twenty-four hours. He found that iron pipes could be disinfected by sulphuric acid without the metal being sensibly attacked.

"The most satisfactory evidence that this spirillum is able to produce cholera in man is afforded by an accidental infection which occurred in Berlin, in the case of a young man who was one of the attendants at the Imperial Board of Health

when cholera cultures were being made for the instruction of students." *

An entirely similar case came under the writer's observation, in Paris, while attending the course at the Pasteur Institute. One of the students, an Italian, was in the habit of constantly smoking cigarettes while at work. He became inoculated with Asiatic cholera through laying down his cigarette in contact with a cholera preparation. He took the typical disease and recovered. A friend of the author's reports a like instance of infection, observed by him while a student in Koch's laboratory.

Pettenkofer and Emmerich each swallowed pure cultures of the comma bacillus, with the result of producing only temporary diarrhœa, and they thereupon claimed that the germ is not to be considered as the cause of cholera. As opposed to this, Roux points out that the pure cultures referred to above may have been attenuated and very far from the point of virulence. Moreover, he shows that, even when truly virulent cultures are swallowed, the disease does not surely result. The author was informed that this point was covered at the Pasteur Institute by the swallowing of virulent germs from the same culture, by Roux, Metchnikoff, and two others. Of these four, three had diarrhœa and one had typical Asiatic cholera.

The President of the National Health Society of England says in a recent address: "We may lay aside all pedantry and mystery talk of epidemic constitution, pandemic waves, telluric influences, cholera blasts, cholera clouds, blue mists, and the like terms of art with which an amiable class of meteorologists has delighted to cloak their ignorance. Cholera is a filth disease carried by filthy people to filthy places. It only develops where it finds dirty places, and the dirty habit of drinking

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* Sternberg's "Manual of Bacteriology," 1893.

polluted water and living on a polluted soil. Cholera does not travel by air-waves or blasts. We drink cholera and we eat cholera, but we cannot catch cholera as we catch measles, scarlatina, or whooping-cough."

"In India, where the water for domestic purposes is impounded in open excavations in the ground, like those near brickyards in this country; in India, where the people wash their soiled clothing by the side of these same tanks, and allow the waste water to flow back into them in innocent disregard of all sanitary laws; in India, where the people deposit all ordure on the surface of the ground, not having in most cases even the pretence of a pit or cesspool; in India, where the people drink the water in which they have just bathed, cholera is never absent. It is not necessary to invoke the currents of the air to explain the constant occurrence, or the terrible virulence of the disease. And yet, in this same India, the people who are brought under the civilization of the West, through the labor of the Christian missionaries, and who adopt new modes of living with their change of religion, escape the cholera as completely as if there were no such disease.

"Cholera is always carried. It never travels on its own account or by its own conveyance, and it is not half so bad a disease as it has been painted by a frightened public.

"It is stated on the authority of the head nurse that not a single case of cholera originated in the hospital of Hamburg during the recent epidemic in that city, though the sick were often placed two in the same bed and the dead in long rows. Amid the gloom and excitement, scores of suspects were hurried off to the hospital who were afterwards found to be suffering from some other disease. Not one of these persons contracted the disease from the cholera patients with whom they were forced to associate. It would seem as if the safest place at the time of a great epidemic of cholera would be where there is the most sickness. All of these statements

point to the fact that cholera is not infectious, and that the danger has been very greatly overestimated." *

"Pettenkoffer has given the key to the whole situation by saying that filth is like gunpowder, for which cholera is a spark. A community had better remove the gunpowder than try to beat off the spark; for in spite of their efforts, however frantic, this may at any time reach the powder, and if it does, is sure to blow them to pieces." (Sedgwick.)

The bacillus of typhoid fever was first described by Eberth in 1880, and more recent investigations tend to confirm the belief in its ætiological relation to the disease. "Pathologists are disposed to accept this bacillus as the veritable 'germ' of typhoid fever, notwithstanding the fact that the final proof that such is the case is still wanting. This final proof would consist in the production in man, or in one of the lower animals, of the specific morbid phenomena which characterize the disease in question, by the introduction of pure cultures of the bacillus into the body of a healthy individual. Evidently it is impracticable to make the test upon man, and thus far we have no satisfactory evidence that any one of the lower animals is subject to the disease as it manifests itself in man." †

Since the writing of this passage by Sternberg, much work has been done by Sanarelli upon artificial typhoid fever, and he has shown that the disease is capable of transmission to animals (see Annales de l'Institut Pasteur). "The period of collapse, that is to say, the last phase of the typhoid infection, is what we produce experimentally in animals. With them the typhoid poison manifests itself too quickly to permit the resistance of the organism to express itself as fever during the early stages of intoxication. If the Eberth bacillus could

* *British Medical Journal.* † Sternberg's "Manual of Bacteriology."

produce its toxin in the human organism with the same intensity that the germs of cholera produce theirs, typhoid fever would become, like cholera, a malady both short and apyretic." (Sanarelli.)

The typhoid bacillus is usually one to three microns long and from 0.5 to 0.8 micron broad. Its ends are rounded. Growth readily takes place at ordinary temperatures in culture media, and the colonies do not liquefy the gelatine. Spores are not produced. In inoculated milk it develops abundantly, a property which has been productive of many serious outbreaks of the disease.

The "germ" is capable of maintaining its existence quite independent of the living animal body, as was proven by Fränkel and Simmonds, who showed that it multiplied in the spleen after death. "This does not in any way weaken the evidence as to the ætiological *rôle* of the bacillus, but simply shows that dead animal matter is a suitable *nidus*." (Sternberg.)

Blythe also consider its probable normal existence that of a saprophyte—i.e., an organism subsisting on decaying organic material.*

There are those who believe, and it is a very conceivable belief, that the progenitor of the typhoid bacillus is often a saprophyte, which takes on its pathogenic properties by cultivation through successive generations, under favorable conditions as to light and temperature, and amid suitable filthy surroundings. Many illustrations are available, in the world of larger vegetables, of great changes in structure and properties due to cultivation under an altered environment. Hansen, the eminent Danish investigator, dealing with unicellular yeasts, has shown that by subjecting these bodies to different environments for a number of generations he can from one

* Blythe, "Manual of Public Health."

original create many so-called species.* Isolated cases of typhoid may be thus accounted for where it would be difficult to suppose contagion from a previously existing case.

In a paper before the British Medical Association, H. R. Kenwood suggests the possibility of the typhoid bacillus being an evolution from the bacillus *coli communis*, an organism ever present in the intestines, and adds that greater changes may be artificially induced, both functional and morphological, in bacteria than are represented by the slight differences between the bacilli in question.

Roux and Rodet hold very strongly that the bacillus *coli communis*, when grown under suitable conditions, may become pathogenic and produce typhoid.† Germano and Maurea arrive at similar conclusions after careful investigations.‡

A full article appears in the Report of the Surgeon-General of the U. S. Army for 1896, page 43, showing the identity of typhoid with the "mountain fever" of the West, and dwelling upon the impossibility of accounting for the development of the disease in an almost untrodden wilderness, except upon the theory that the *bacillus typhosus* is capable of derivation from a saprophytic source.

Remlinger and Schneider published an article in the Journal of the Pasteur Institute, February, 1897, on "The Ubiquity of the Typhoid Bacillus," in which they conclude that "the *bacillus typhosus* is distributed in nature outside the human body," and they "incline to think that bacilli not pathogenic, and indifferent to the serum test, which are encountered in water and soil are only definitive types of the *bacillus typhosus;* at least the parentage is evident even if the identity is not absolute." §

* See Bul. N. C. Board Health, xvi. 100.

† *Analyst*, xxi. 118.

‡ *Central. für Bakteriologie*, xv. 60.

§ In this connection see an article by F. C. Curtis on "Life-history of the Typhoid-fever Germ outside the Body," *Albany Med. Annals*, xviii. 167.

It must not be assumed that those who favor the view of a saprophytic ancestry for the typhoid germ have the argument all their own way. Far from it. Perhaps the bulk of bacteriologists are ranged upon the other side; * but, while the specialists are searching for further light upon this question, the evolution, or saprophyte, theory is a good working formula for the sanitarian, and upon it he should for the present rest, remembering that typhoid fever and filth are very closely related.

The great influence of light upon the growth of the typhoid germ has been demonstrated by Janowski, who found that freshly inoculated gelatine, if kept in the dark, developed colonies in three days; if placed in diffused daylight, growth occurred in five days; but if the exposure were to direct sunlight for six hours, the gelatine became sterile.

This inability to survive long exposure to sunlight in presence of air is not peculiar to the typhoid bacillus. Fortunately for us, such sterilizing action is of wide application, and is one of nature's chief lines of defence against overwhelming bacterial invasion. A simple illustration, showing the inhibiting action of sunlight toward such common bacteria as liquefy culture-jelly, may be readily made as follows: Pour some melted jelly, previously inoculated with a drop of broken-down culture medium, into a Petri dish, upon the bottom of which have been pasted letters cut from black paper. When the jelly has set, expose the inverted dish for several hours in a cool place to the bright sunlight. After exposure, place the preparation in the dark, at the usual culture temperature (22° C.). Liquefaction will be found to take place only in the portions shaded by the paper, and the letters will be found sharply countersunk in the jelly.

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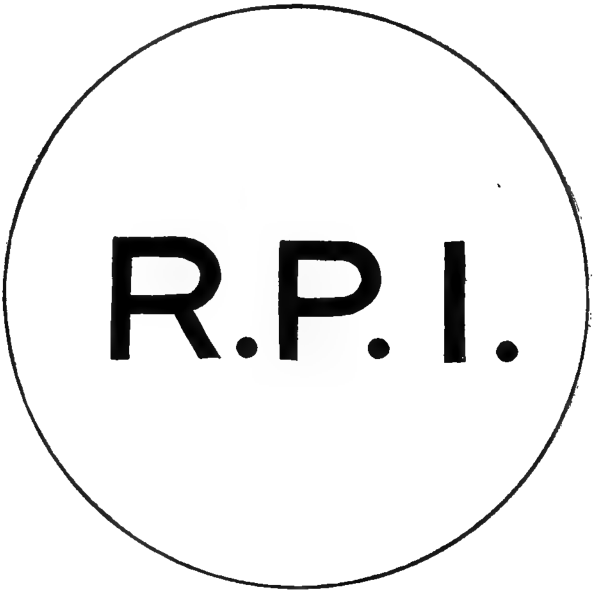
* E.g., Sedgwick in *J. N. E. Water-works Asso.*, xi. 255.

All bacteria are not killed by direct sunlight as, for instance, *B. photometricum*.*



ILLUSTRATING STERILIZING ACTION OF SUNLIGHT.

Burnett found that the water furnished to Colombo, in the island of Ceylon, although not of high quality from a chemical point of view, rarely contained more than two microbes per cubic centimetre. As the supply is from extensive, shallow surface-waters, the explanation is offered that nearly complete sterilization results from prolonged exposure to the direct rays of the tropical sun.†

It is generally observed that the number of bacteria in river-water is less in summer than in winter, but it must not be hastily concluded that this is due to the sterilizing action of light. As is shown upon another page, the summer feeders

* Hueppe, "Principles of Bacteriology," 61; also a paper by Wesbrook, *J. Pathology and Bacteriology*, London, vol. iii. No. 4.

† *Chem: News*, lxx. 285.

are commonly springs, while in winter much impure surface washing reaches the streams. Moreover, the action of light does not penetrate the water to any considerable depth.

Sternberg, and also Janowski, found the thermal death-point of the bacillus to be 56° C. (132.8° F.), the time of exposure having been ten minutes.

Typhoid bacilli are not destroyed by extreme cold.* The epidemic at Plymouth, Pa., in 1885, is a case in point. As we have seen (page 37), the outbreak was traced to the dejecta of a single patient, which had been thrown upon the frozen ground and snow, during the early part of January, and which remained there until washed into the stream by the thaw occurring on March 26th. During this period the temperature had fallen to 22° F. below zero.

Very similar to the Plymouth outbreak is the one which occurred at Windsor, Vt., a town of some 2000 inhabitants, during the spring of 1894. For several weeks the typhoid germs remained in a frozen state, without having their potency in the least impaired.†

Prudden found the germ capable of development after having been frozen in ice for over one hundred days, and he also made the interesting observation that alternate freezing and thawing proved fatal to it.

An experiment was undertaken at the Lawrence experiment station to determine the viability of the typhoid bacillus in water near the freezing-point. After specific inoculation, the river-water was placed in a bottle surrounded with ice, and a portion was removed daily for examination, with the following results:

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* See page 225.

† It is well to remember that the urine of a typhoid patient is infectious as well as the fæces. *Phila. Med. J.*, i. 959.

1st day	....	6120	germs	per	cubic	centimetre
5th "	....	3100	"	"	"	"
10th "	....	490	"	"	"	"
15th "	....	100	"	"	"	"
20th "	....	17	"	"	"	"
25th "	....	0	"	"	"	"

Some few survived until the twenty-fourth day.

"The typhoid bacillus retains its vitality for many months in cultures. The writer has preserved bouillon cultures for more than a year in hermetically sealed tubes, and has found that development promptly occurred in nutrient gelatine inoculated from these. Dried upon a cover-glass, it may grow in a suitable medium after having been preserved for eight to ten weeks. When added to sterilized distilled water it may retain its vitality for more than four weeks, and in sterilized sea-water for ten days. Added to putrefying fæces it may preserve its vitality for several months; in typhoid stools for three months; and in earth, upon which bouillon cultures had been poured, for five and one-half months." *

At a mill at Canton, Mass., in June, 1888, out of 120 men some 50 were taken with typhoid. The families of these men were not affected. The drinking-water of the mill was from a well on the opposite side of a ledge and 54 feet distant from a privy-vault, which latter had received typhoid dejecta eight months previously. By experimenting with salt, direct connection by infiltration from vault was shown. Note the time-element in this case.—*J. New Eng. Water-works Asso.*, v. 150.

As to the longevity of the typhoid bacillus in water, it is now generally admitted that such a medium is not favorable to its growth, and that although it may survive for varying periods, the length thereof depending upon local conditions, it rarely, if ever, increases in numbers and ultimately dies.

* Sternberg, "Manual of Bacteriology."

Percy Frankland found that it would live in Thames water (London) for seventy-five days. E. O. Jordan kept it alive for ninety days in water from Lake Michigan (Chicago), and Hill found the time-limit to lie between sixty and ninety days in Ohio River water (Cincinnati).

Mills had previously reported the vital period to be from seven to twenty-one days in Merrimack River water, and pointed out that this short period of existence presents the probable reason why the fever may be readily carried down a river from city to city, while a polluted stream may enter one end of a large pond, whose waters are changed only after months, and a water-supply drawn from the opposite end may be continually free from specific pollution.*

One important point to be remembered is the antagonism between the disease germ and the common bacteria so largely found in surface-water. While such antagonism has been broadly noticed, Percy Frankland has placed the demonstration in the following form. He introduced typhoid bacilli into deep-well water which was almost wholly free from bacteria, into Thames water which contained a large number, and into Loch Katrine water in which the number was intermediate between the two. He found that the typhoid bacilli died off more rapidly in Thames than in Loch Katrine water, while they persisted longest in the sparsely populated deep-well water. Thus the longevity of these pathogenic bacteria was inversely proportional to the bacterial population in the waters into which they were introduced.† Thus we see that a relatively pure stream, if a rapid one, might carry infection over long distances.

It would appear that the conditions under which typhoid fever occurs obtain more frequently in the country than in large cities. This statement is hardly in accord with popular belief,

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* Am. Soc. C. E., xxx. 364. † *Water and Gas Review*, Jan. 1897.

but a study of the following statistics will show it to be true for the State of New York:

ANNUAL TYPHOID DEATH-RATE, PER 100,000 INHABITANTS, FOR THE YEAR 1900.

	Population per Square Mile.	
For the maritime district	1685	20.38
" " Hudson Valley district	118	50.00
" " Adirondack & Northern dist.	26	39.00
" " Mohawk Valley district	86	35.19
" " Southern Tier "	65	33.17
" " East Central "	62	27.04
" " West Central "	67	28.00
" " Lake Ontario & Western dist.	200	23.76
" " whole State	145	27.40
" " largest six New York cities		22.46
" " 'rest of district' *		25.10

The difference here observed must be largely due to the greater care exercised in the selection of a water-supply for a city, as compared with that so frequently displayed in the sinking of a country well. It would seem that a due saving of the steps of the housewife is all that the average farmer thinks about when selecting a site for his well, and he digs it in the most convenient position, and entirely without regard to local surroundings. The writer saw one domestic supply drawn from a tall pump, which was nearly covered by a manure heap of so great proportions that the pump-handle had to be extended by splicing a stick thereon in order to permit of its being reached. The water was caught in a small trough extending over, and resting upon, the top of the manure pile.

The maintenance of the water-supply in a pure state, however, is not of itself enough to eliminate typhoid fever. The

* The expression 'rest of district' is used to cover that portion of the sanitary district yet remaining after the cities, towns, and villages have been accounted for. It embraces the most rural portion of the community.

local hygienic conditions must be good as well, otherwise the resisting powers of the human organism will be lowered and left unable to oppose the invading germs, which may come from some other source.

In work by Sanarelli conducted at the Pasteur Institute, Paris, this point is well covered. He shows that if animals are previously injected with the toxins of certain bacteria, such as *coli communis*, they afterwards succumb to inoculation with Eberth bacillus with complete symptoms of typhoid.

Other experiments point towards the obtaining of similar results, when the animals are inoculated with typhoid culture, after they have been compelled for a certain time to breathe air laden with putrefactive materials.

The following table gives the results of experiments made by Dr. Alessi at the University of Rome to determine the influence of exposure to foul gases upon animals subsequently inoculated with culture of typhoid bacillus. The rats were exposed to sewer gas by placing them in a box, the wire bottom of which closed the aperture of an untrapped water-closet. The guinea-pigs and rabbits were placed in a box, the wire bottom of which rested on a vessel which contained excrementitious matter.*

	Culture used for Inoculating the Animals.	Kind and Number of Animals Inoculated.	Percentage of Mortality among the Animals Inoculated.	
			Animals exposed to Foul Gases previous to Inoculation.	Control Animals kept under Normal Conditions.
1st series..	Typhoid........	90 rats.........	75.5%	7.3%
		122 guinea-pigs..	79.2	0.0
		18 rabbits......	100.0	0.0
2d series...	Typhoid........	46 guinea-pigs..	77.8	0.0
		14 rabbits......	87.5	0.0
3d series...	B.coli communis..	22 guinea-pigs..	83.3	0.0

As tending in the same direction, Nocard and Roux "found by experiment that an attenuated culture of the anthrax bacillus, which was not fatal to guinea-pigs, killed

* J. Sanitary Inst., xvi. 487; also Roechling, "Sewer-gas and Health," p. 120.

these animals when injected into the muscles of the thigh after they had been bruised by mechanical violence. Charrin and Roger found that white rats, which are unsusceptible to anthrax, became infected and frequently died if they were exhausted, previous to inoculation, by being compelled to turn a revolving wheel. Pasteur found that fowls, which have a natural immunity against anthrax, become infected and perish if they are subjected to artificial refrigeration after inoculation." (Sternberg.)

The foregoing experimental results are very suggestive, and bear directly upon the relation of unsanitary surroundings to the development of typhoid.*

From both experiment and experience we are forced to conclude that "good water" and "clean surroundings" go hand in hand in protecting the people against typhoid fever and cholera. The following table was prepared by Dr. E. F. Smith in support of this proposition:

TYPHOID AND CHOLERA IN BUDAPEST, 1863–77.

1. *Influence of filthy houses:*		
Deaths from cholera per 100 houses when the interior of the DWELLING was	1. Very clean	92
	2. Clean	199
	3. Dirty	268
	4. Very dirty	402
Deaths from typhoid fever per 100 houses when the interior of the DWELLING was	1. Very clean	165
	2. Clean	177
	3. Dirty	182
	4. Very dirty	356
2. *Influence of filthy yards:*		
Cholera deaths per 100 houses when the YARD was	1. Very clean	188
	2. Clean	214
	3. Dirty	263
	4. Very dirty	389
Typhoid fever deaths per 100 houses when the YARD was	1. Very clean	159
	2. Clean	186
	3. Dirty	208
	4. Very dirty	282

* For complete statistics showing relation of typhoid fever to sewer-gas, see "Sewer-gas and its Influence upon Health," by H. A. Roechling, 1898; also *Nature*, vol. l. p. 19.

Another tabulation from the same source is here given:

MEAN ANNUAL DEATH-RATE IN UNSEWERED AND SEWERED CITIES IN RECENT YEARS.

	City.	Period Included.	Rate per 1000 Living.
Unsewered.	New Orleans	20 years, 1865–84	33.4
	Baltimore	15 years, 1870–84	25.3
	Charleston, S. C.	5 years, 1880–84	34.6
	Mexico	2 years, 1876 and 1878	52.0
	Madrid	1881.	37.4
	Marseilles	5 years, 1880–84	31.0
	Naples	7 years, 1878–84	32.8
	Turin	20 years, 1865–1884	27.2
	Palermo	7 years, 1878–84	24.5
	Budapest	10 years, 1870–79	42.7
	Moscow	2 years, 1879 and 1880	39.9
	Riga	13 years, 1870–1882	28.8
	St. Petersburg	Recent years	40.0
	Pekin	Recent years	50.0
	Cairo	Recent years	37.0
	Average		35.8

	City.	Period Included.	Rate per 1000 Living.
Sewered.	London	20 years, 1865–84	22.7
	Twenty large English cities	10 years, 1869–78	24.9
	Glasgow	10 years, 1871–80	28.1
	Edinburgh	Average of 5 years, 1874, '78, '79, '83, '84	20.9
	Brussels	10 years, 1875–84	26.3
	Berlin	15 years, 1870–84	30.5
	Breslau	10 years, 1875–84	31.7
	Hamburg	10 years, 1875–84	25.0
	Dantzic	10 years, 1875–84	28.9
	Frankfort	20 years, 1865–84	20.4
	Munich	10 years, 1875–84	33.7
	New York	20 years, 1865–84	28.0
	Brooklyn	15 years, 1870–84	24.1
	Boston	20 years, 1865–84	23.9
	Chicago	20 years, 1865–84	21.5
	Average		26.0

An analysis was made by the Michigan State Board of Health of the sources whence typhoid fever was derived in that State, and the results are given in the following table:

TABLE EXHIBITING THE REPORTED "SOURCE OF CONTAGIUM" OF CASES OF TYPHOID FEVER IN MICHIGAN DURING THE YEAR 1891.

Reported Sources.	Number of Cases.
Traced to former cases	322
Probably traced to former cases	2
Attributed to infected, contaminated, or surface water	1477
Attributed to drinking infected or impure milk	8
Cases reported as coming from outside jurisdictions	192
Attributed to defective sewerage or drainage	44
" " filthy or unsanitary conditions	117
" " going in swimming and going in water	2
" " stagnant water	9
" " malaria	8
" " overwork	3
" " *la grippe*	3
" " taking cold	2
Cases reported as "sporadic"	9
" " to have arisen *de novo* (1 "spontaneous," and 6 "local")	18
Cases the sources of contagium of which were reported as unknown	560
Cases the sources of contagium of which were not reported, or the statements were too indefinite for classification	1894
Total	4670

After all sources of possible danger have been examined, it must be admitted that outlying isolated cases of typhoid fever are often difficult to explain; but it should not be forgotten that the disease does not manifest itself until a considerable time after infection, the incubation-period being usually about fourteen days, and therefore the possibility of its having been imported should be always borne in mind.

"After the reception of the infection, there is, in all communicable diseases, an interval during which the patient remains in apparent health, or perceives at the most some languor. This period lasts from one to five days in the case of cholera. For typhoid fever its duration varies from nine days to three weeks. The latter disease begins so gradually that the patient generally does not come under the observation of a physician until he has had the fever for several days. If water infected by typhoid-fever dejecta were to be drunk by a considerable number of persons August first, the first case would appear about the ninth or tenth, and fresh cases would continue to appear until the twenty-third. There would be more on the fourteenth or fifteenth than at any other time. The deaths would nearly all occur the next month—September. These laws of development are of great aid in discovering the cause of brief epidemics, by indicating the period in which it must have been common to all the persons attacked." (E. J. Matson.)

An argument always advanced against the proposition that a typhoid epidemic in a town is to be accounted for by the use of a contaminated water-supply is that only a few of the inhabitants are attacked, while all use the water. Why should the majority escape? For full discussion of the wide subject of "immunity," thus introduced, the reader must be referred to the extensive monographs written thereon; but let it be here said that recent investigations tend to support the view, advanced by Sternberg in 1881, that immunity depends upon an inherited or acquired tolerance to the toxic products of pathogenic bacteria.

He shows how putrefactive bacteria, introduced into drawn blood, maintained artificially at body temperature, will quickly multiply and produce decomposition, while the same "dose" of bacteria injected into the circulation of a living animal will rapidly disappear and leave no trace.

So likewise, in many cases, with pathogenic organisms. The invading bacterium is seized upon by the guardian leucocytes of the blood, and destroyed by a process of assimilation, provided "the captors are not paralyzed by some potent poison evolved by their prisoner, or overwhelmed by its superior vigor and rapid multiplication."

A single disease-germ may prove fatal, as has been shown by Cheyne, who experimented upon guinea-pigs with anthrax;* but if any considerable degree of vital resistance be present, the "bacterial dose" may have to be very greatly enlarged to produce observable effects. Thus the above investigator found that "for rabbits the fatal dose of the microbe of fowl cholera is 300,000 or more, that from 10,000 to 300,000 cause a local abscess, and that less than 10,000 produce no appreciable effect." He found 225,000,000 of the *Proteus vulgaris* fatal to rabbits, but that less than 9,000,000 gave an entirely negative result.

Another interesting point that arises in this connection is the wide difference between the intensity of the attacks induced by a "virulent" and an "attenuated virus." It is well known that, if the conditions attending the cultivation of a pathogenic microbe be unfavorable to its ready growth, if they be just short of the death-point, if the germ be obliged to struggle for existence through successive generations, the result is an organism of less vigorous constitution, and one capable of producing only a fraction of the amount of "toxin" elaborated by its sturdy progenitor.

Inoculation with such "attenuated virus" might be fatal to the very susceptible, but a larger number of the resistant portion of the community would escape, and the great majority of all cases occurring would be designated as "mild."

We constantly hear of the great preponderance of "mild" cases reported during the prevalence of city epidemics of

* See also "Principles of Bacteriology," by Hueppe, Trans. by Jordan, page 152.

typhoid fever, and our thoughts naturally turn to attenuation of virulence caused by unfavorable surroundings (e.g., the conditions of water-carriage) as an explanation of the observed fact.

Typhoid fever is essentially an autumn disease, occurring after the heat and drought of summer have made severe inroads upon the ground-water supply. Thus we find the following record:

DEATHS FROM TYPHOID AND TYPHO-MALARIAL FEVERS IN CONNECTICUT FOR EIGHT YEARS, ARRANGED BY MONTHS.

(From the State Board of Health.)

	1883	1884	1885	1886	1887	1888	1889	1890	Average 1883–1890
January	20	31	20	13	14	11	24	26	19.9
February	15	14	15	9	10	11	13	18	13.1
March	20	15	19	18	13	16	19	11	16.4
April	22	20	17	15	12	8	13	17	15.5
May	24	16	8	23	12	17	16	15	16.4
June	13	15	13	11	8	9	13	13	11.9
July	23	19	30	16	13	17	29	20	20.9
August	67	46	37	51	30	36	47	35	43.6
September	61	51	49	43	34	58	49	49	49.2
October	78	72	39	39	28	75	49	60	55.0
November	45	55	31	35	27	31	30	41	36.9
December	48	25	17	25	24	25	12	23	24.9
Total	436	379	295	298	225	314	314	328	323.7

The prevalence of typhoid during the autumn, as shown by the above table, is also illustrated by the returns of the N. Y. State Board of Health for the year 1898.

The number of deaths from typhoid fever, as reported by months, was as follows:

January	122	July	89
February	104	August	181
March	119	September	333
April	80	October	281
May	86	November	189
June	70	December	156

The first, or at least one of the first, to call attention to the relation between water and typhoid fever was Dr. Michel, of Chaumont, France.* In 1855 he observed that typhoid, which was epidemic in the above place, varied in number of cases and in intensity inversely as the quantity of water in the public wells.

Pettenkofer, of Munich, about the same time, undertook extended observations upon variations in the height of ground-water, and, a little later, relationship was shown between these variations and the occurrence of typhoid fever.

Those who hold with Pettenkofer claim that the elements of the disease readily multiply in the soil, and are driven therefrom, along with the ground-air, upon the rising of the water-level at the time of the autumnal rains.

Latham, in speaking upon this point, says:

"No great variation in the vertical rise and fall of subsoil water is the healthier condition. The ground always contains air, and, as the ground-water sinks, air is drawn in to supply its place. After long dry weather the air of the soil is thus laden with products of decomposition. A rain now occurring, the ground-air is displaced, and since said rain is liable to seal the surface, the tendency of the air is to escape laterally, i.e., into cellars. Dry summers invariably mark unhealthy years. Typhoid fever occurs after the autumn rains.

"All the great epidemics of typhoid have occurred in years when the ground-water was especially low, and after a slight rise in the same."

Pettenkofer's "ground-air theory" is not gaining the majority of supporters, a more reasonable view being that, as the water-surface lowers in a well, the base of the cone of drainage, whose apex is at that surface, is extended, and consequently more widely situated points of pollution are embraced within its influence.

* "Influence de l'eau potable sur la santé publique." Paris, 1889.

Perhaps the most exhaustive examination of the relation of the height of ground-water to the prevalence of typhoid fever that has been made in America is to be found in the work of the State Board of Health of Michigan.

Observations have been made by that board during a period of many years, and the height of the water in a representative well near the centre of the State has been regularly measured. The results, graphically shown herewith (see page 83), indicate in a very marked manner that increase of typhoid and lowness of water in wells move in practically the same curve of variation.

The statistics go to show that in October, 1894, the water in the standard well stood eleven inches lower than in October, 1893, and seven inches lower than the October average for the eight years 1886–1893.

For September, 1894, typhoid fever was reported from 121 places in the State, an increase of forty-six places over the report for September, 1893.

For October, 1894, typhoid was present at 165 places, as against 109 for the same month of 1893, and the prevalence of the disease was forty-four per cent above the October average for the eight years 1886–1893.

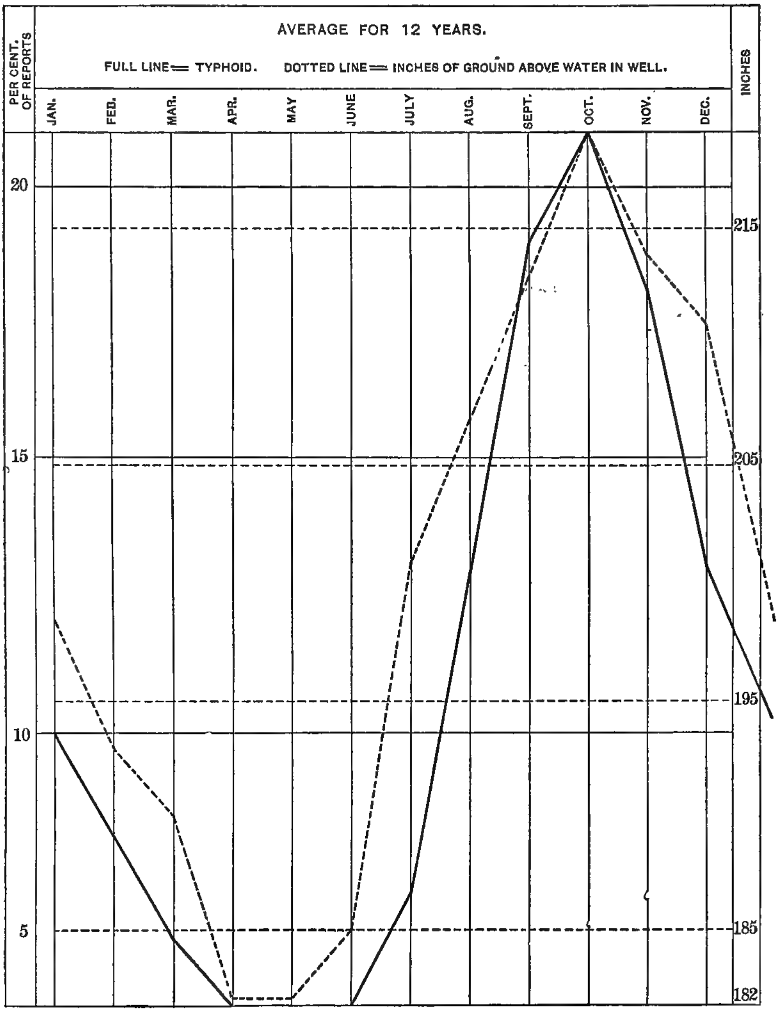
During the three months of September, October, and November, 1894, the ground-water of Michigan grew constantly lower.

It is difficult to see just how these data could be made to fit the "ground-air" theory of Pettenkofer or Latham as a cause of typhoid fever; for such theory calls for sudden rise in ground-water level rather than continued lowness thereof.

A somewhat extended inquiry was made by the writer * with the view of determining whether or not other States shared the experience of Michigan with reference to the effect of low ground-water.

* See former editions of this book for full description.

The Western States, so far as heard from, appeared to follow the "Michigan rule," but New York, Connecticut, and Massachusetts were manifest exceptions thereto.



COINCIDENCE OF PREVALENCE OF TYPHOID FEVER AND LOWNESS OF WATER IN WELLS. (STATE OF MICHIGAN.)

While not wishing to dogmatize upon too scanty data, the suggestion is offered that, so far as these three States are con-

cerned, larger shares of their populations derive their drinking-water from more or less carefully selected sources of public supply, and are consequently less exposed to the danger arising from the local contamination of private wells.

Whether the exhaustive study of facts does or does not support the view that the relation of typhoid fever and rainfall, so far as ground-water is concerned, deals with the question of low ground-water, rather than with fluctuations in its vertical height, it admits of ready illustration that marked relationship certainly exists between this disease and the sudden influx of storm-waters, flooding the polluted foreshores of smaller rivers. We have seen such a case in the epidemic of typhoid in the valley of the Tees, page 32.

However much the statistics referring to Asiatic cholera and to typhoid fever may be considered as especial indicators of the purity of a town's water-supply, it must not be supposed that the general death-rate is unworthy of careful study as well.

It is widely known that the present potable supply for Paris is vastly superior to the water from the Seine, which formerly was all that the inhabitants had for domestic use. The following figures, giving the total death-rate for a group of five years before the introduction of the purer water and for a similar period after the Seine had been abandoned for drinking purposes, well illustrate the benefit of the change:

	Total Deaths.	Rate per Thousand.	Average.
1860	41,261	24.32	
1861	43,664	25.74	
1862	42,185	24.87	24.57
1863	42,582	23.33	
1864	44,913	24.60	

	Total Deaths.	Rate per Thousand.	Average.
1888	53,303	21.99	22.89
1889	56,059	23.12	
1890	56,660	23.37	
1891	54,443	22.45	
1892	57,137	23.53	

These averages show a saving of 1.68 per thousand, or, based on the last-stated population of 2,424,705, they represent the preservation of 4072 lives annually in the city of Paris.

Still more striking are the statistics furnished by San Remo, a town of 18,000 inhabitants, situated upon the Italian Riviera. The present superb water-supply (introduced December, 1883) comes from the mountains, and is one of the best in Europe, while the former one was derived from shallow domestic wells sunk into a filthy city soil. The following table for total death-rate is interesting:

	Total Deaths.	Rate per Thousand.	Average.
1879	362	22.37	22.61
1880	368	22.74	
1881	320	19.75	
1882	347	21.30	
1883	441	26.91	
1884	312	18.91	19.65
1885	409	24.65	
1886	334	20.10	
1887	331	19.81	
1888	270	15.90	
1889	353	20.37	
1890	307	17.34	
1891	317	17.92	
1892	352	19.83	

It will be observed from the above averages that the total death-rate has been lowered a trifle over 13 per cent by the

introduction of pure water. Still more striking is a statement made to the author by Dr. Martemuci, the leading local physician. He said: "Where I now have one typhoid case, I had forty before the change in the water-supply."

An entirely similar statement was made to the writer by Dr. Barringer of Naples, with reference to the improvement in typhoid death-rates with a better water system in the latter city

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As cities increase in size there are introduced into the total death-rate disturbing factors that must be considered in comprehensive study. Thus the influence of simple crowding is well illustrated by the following statistics for various London districts:*

		Mean Death-rate, 1885-91.
Districts with a density of	under 40 persons per acre...	15.27
Do.	from 40 to 80...........	19.04
Do.	from 80 to 120...........	19.24
Do.	from 120 to 160....	22.60
Do.	over 160.................	23.88
County of London, with a density of	over 57.........	19.90

Finally, in view of the intensely practical spirit of the age, let us consider the question,

Does pure water pay?

To abandon an existing water-supply system, or to purify the polluted water that it furnishes, always involves the outlay of much money, and the city taxpayer has the right to inquire whether or not the benefit derived is a fair equivalent for the cash expended.

Typhoid fever is doubtless, to a large extent, a preventable

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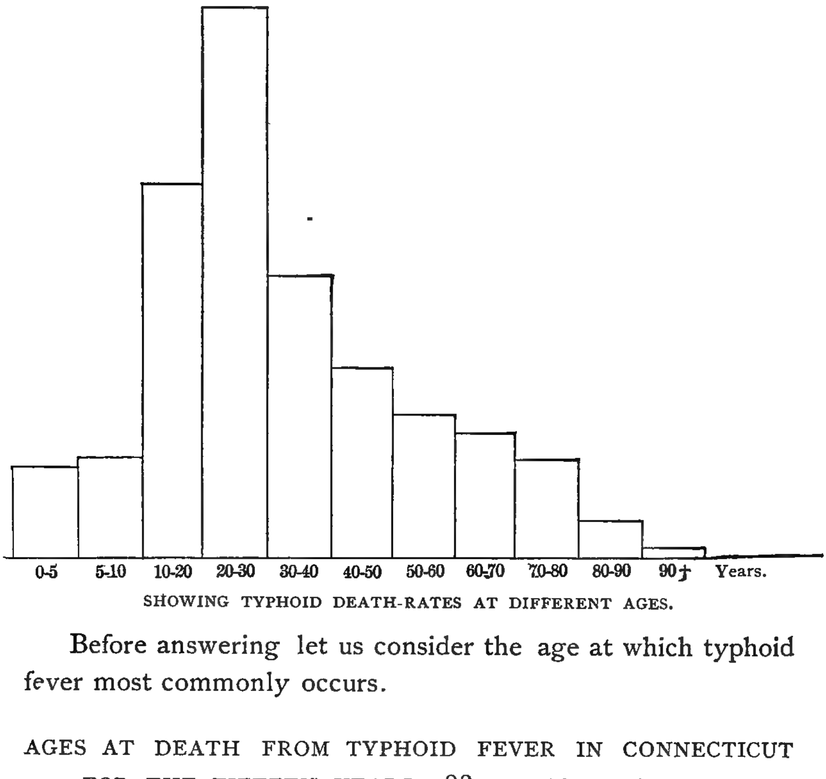
* *Engineering News*, Dec. 28, 1893.

disease, but the means of prevention, in the shape of great public works, are expensive, and the question is very properly asked, Do these works pay? Can we afford to save the typhoid victims?



SHOWING TYPHOID DEATH-RATES AT DIFFERENT AGES.

Before answering let us consider the age at which typhoid fever most commonly occurs.

AGES AT DEATH FROM TYPHOID FEVER IN CONNECTICUT FOR THE FIFTEEN YEARS 1880–94 AS PERCENTAGE OF TOTAL TYPHOID DEATHS.

(Shown also graphically above.)*

Under 5 years	4.7	per cent
5–10 "	5.0	"
10–20 "	18.6	"
20–30 "	27.7	"

* Rep. Conn. Board of Health, 1895, p. 165.

30–40 years	14.0	per cent
40–50 "	9.5	"
50–60 "	6.9	"
67–70 "	6.3	"
70–80 "	4.8	"
80–90 "	1.9	"
Over 90 "	0.3	"
Not stated	0.3	"
	100.0	per cent

According to Rochard, the economic value of an individual "is what he has cost his family, the community, or the State for his living, development, and education. It is the loan which the individual has made from the social capital in order to reach the age when he can restore it by his labor."

The statement of this value, in form of money, is a difficult matter, which has been variously settled by sundry investigators. Chadwick considers an English laborer equivalent to a permanent deposit of £200 (say $980). Farr gives £159 (say $780) as the average value of each human life in England. A French soldier is rated as worth 6000 francs (say $1200).

In view of the fact that typhoid fever selects by far the greatest number of its victims from among those in the very prime of life, to the relative exclusion of the very young and the very old, it will be reasonable to follow the figure fixed upon by E. F. Smith, and place the loss caused the community by a death from typhoid at $2000. This will be noticed to be less than half the figure so frequently referred to in the courts of this State for the value of a human life.

For the sake of illustration, let us consider the tax formerly levied annually by typhoid fever upon the city of Albany, N. Y.*

* Albany has recently introduced a modern and efficient filter-plant. See page 109. The typhoid rate for 1900 was 39 per 100,000.

The population of Albany is about one hundred thousand, and from statistics given in the reports of the State Board of Health the deaths due to typhoid fever in Albany formerly averaged seventy-five for the year.

Rating the money value of each life at the figure given above, this death-rate would mean an annual pecuniary loss to the city of $150,000.

Funeral expenses are variously estimated at from $20 to $30. Should we accept the intermediate value of $25, this item would cause $1875 to be added to the above sum, thus raising the total direct loss through death to $151,875.

But typhoid fever does not always kill. Its mortality rate is commonly quoted at about ten per cent. For the present purpose, should we assume nine recoveries for each death from the disease, and place 43 days as the period of convalescence (the average of 500 cases at the Pennsylvania Hospital), we should have a term of 29,025 days as representing the time lost, per year, by the 675 persons who have the fever and recover. Thus an annual loss of over 79 years had to be borne by the city's capital of productive labor.

This great amount of enforced idleness, when translated into money value, should very properly be added to the death-loss above estimated.

Fixing the rate of wages at $1 per individual per day—a very low figure, considering that the bulk of typhoid patients are in the very prime of life—there was a loss of $43 of wages for each recovery, or a total yearly loss for the city from this item of $29,025. The cost of nursing and doctors' bills equal at least $25 per case, which is a very low estimate, thus adding the further amount of $16,875 to the gross sum. Expressed in tabular form, this yearly tax imposed by typhoid fever upon the city of Albany is given below, and, upon a most conservative estimate, it is practically $200,000, which was $2 a year

for each man, woman, and child in the city, or a yearly tax of $10 for every family of five persons.

75 deaths at $2000 each..........	$150,000
75 funerals at $25 each.	1,875
Wages of 675 convalescents during 43 days at $1 per day.......	29,025
Nursing and doctors' bills for 675 convalescents at $25 each case.........................	16,875
Total tax formerly levied annually by typhoid fever upon the city of Albany...	$197,775

It can readily be seen that public works which could eliminate a reasonable fraction of this great tax would pay for themselves in the course of a few years, even though they were originally expensive.

A further item of cost, moreover, appears to be coming in the near future, namely, that of "damages" for wanton destruction of life.

A claim of this character has been successfully made against one Western water company, and it may be followed by many others. Even indictments for manslaughter are not unknown.

In a recent paper by J. J. Hoppes he very tersely referred to the fact that the comparatively few deaths from typhoid fever in the army during the Spanish war had stirred up the newspapers to much comment and criticism, while they scarcely mention that 40,000 deaths from this disease occur annually in the United States, and many times that number of cases.

Finally, it is right to inquire what fraction of the present typhoid loss it would be reasonable to hope to save if pure water should be served to a city in place of its present polluted supply. To answer this question recourse must be had to statistics obtained from sundry places, covering periods before

and after better water systems had been introduced. Such data have been already given for a number of communities, and it only remains to anticipate what will be later said of Munich, and state that improved water and sewerage have reduced the annual typhoid mortality from an average of 254 per 100,000 to 27.

Surely pure water pays in a city with such a record, and likewise it would pay in the newer but growing cities on this side of the Atlantic. Americans insist upon being supplied with much more water *per capita* than is usually furnished in Europe, but they are singularly indifferent as to its quality. It would be a reform of great moment if they could be induced to curtail the present enormous waste of public water, such as that of Buffalo, for instance, which is 70 per cent of the entire pumpage,* and to expend the money thus permitted to leak away in a vigorous effort to improve the quality of the supply. No such lowering of the typhoid death-rate as occurred at Munich, San Remo, and sundry other places could be looked for, perhaps, but a large percentage of the present rate could be cut off, and we think, from a consideration of the above figures, that such a reduction would pay.

No weight should be attached to the argument, so often advanced by the individual householder, that he and his family "have used the water without evil result for fifty years." A single family is too small a collection of units upon which to base any estimate touching the question at issue.

Placing the former typhoid death-rate for Albany, as above, at seventy-five annually, it would call for one death in a family of five persons every 261 years, a period much beyond the limits of ordinary family record.

This argument of "experience" is frequently used to defend wells whose purity has been questioned by the inspector.

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* *J. N. E. Water-works Asso.*, xiv. 212.

It must be remembered that a well which is polluted by sewage material may furnish, during long periods of time, a water which is not disease-producing; and yet it may suddenly become very dangerous because of the introduction of infected sewage derived from a newly developed, and possibly imported, case of typhoid fever.

In view of the difficulty, so often encountered, of interpreting the terms found in many water contracts, it is well, before closing this chapter, to inquire

What is a "good, pure, wholesome" water?

Adjectives such as the above, with the occasional addition of the expression "clear," are commonly found in the contracts made by private water companies with the cities which it is their business to supply.

Litigation over an alleged violation of such a contract having been instituted, it usually becomes the duty of some expert witness to pass upon the question as to whether or not the water under consideration is of such a quality as to fall within the limits specified by the wording of the agreement.

To the average layman there would appear to be no ambiguity in describing a water as "good, pure, and wholesome," and he would see no objection to demanding that the words be descriptive of every public water-supply in the country, and that the water companies, wherever located, be forced to live up to the exact and literal meaning of each and all of those words.

To show, however, that the above expressions are somewhat loosely used and that they lack in the definiteness which is expected of them, let us consider them separately for a moment.

What is a "good" water? Surely before answering we

must inquire: "Good for what?" If for drinking, then its consideration would properly come later when we dwell upon the expression "wholesome." Outside of the question of potability, a water charged with calcium sulphate may be very "good" for the brewing of light ale and very "bad" for either boiler or laundry use. It is to the selenitic character of its water that Burton-on-Trent largely owes its reputation as a great ale-producing centre, for the properties which are so popular in the brews of Bass and Allsopp seem to depend upon the presence of calcium sulphate in the water from which they are made. Such a water would, however, be very unacceptable to the large laundry interests of Troy, N. Y., where the daily soap-consumption is measured by the ton.

Perhaps the most striking instance of complaint against a "good" water, a water really excellent at its point of collection, is reported in a recent issue of *Stahl und Eisen*.

It seems that at Johann-on-the-Saar a soft and very pure water, highly charged with carbonic-acid gas, and most desirable for drinking purposes, became brown and unfit for use after passing through the street-mains, because of the action upon the metal by the gas in question. Here, then, is a water of such high worth that any citizen would be glad to have it furnished for his table, and yet it is so damaged by the iron piping of the streets as to reach the consumer in a most unacceptable condition. The city mains are hardly to blame, for they are much the same the world over. Now how should we rate such a water, "good" or "bad," if we were called upon to interpret the wording of a contract in a closely contested case?

In a water controversy with which the writer was once connected, the responsibility of the water company ended at the city's reservoir, distribution being attended to by the municipal authorities. Now let us suppose that the character of the water in that instance had been similar to the German

one above quoted, would it not have been highly probable that the water company would have insisted that the supply as they delivered it was eminently "good" and that they had consequently discharged their whole duty to the town?

As with "good," so with the word "pure." It is, as used, extremely ambiguous. Strictly pure water is a chemical curiosity, very difficult to prepare and perhaps still harder to preserve, as all know who have read about Sir Humphry Davy's classic determination of its composition. The word in the contract manifestly cannot mean water such as that; but if not, then what does it mean? If some permissible limit of impurity be implied, what is that limit and what is the character of the permissible impurity? These are fair questions, and they are pressing for an answer.

We turn now towards the expression "wholesome," trusting that here at least we have a definite term concerning which no misunderstanding can arise. It certainly does sustain more close scrutiny than the two already considered; but even this word, of apparently clear meaning, may be quite befogged by considerations that remind us of the old adage, "What is one man's meat is another man's poison."

How often we note that a change from a soft to a hard water, or *vice versa*, is followed by intestinal derangements, particularly among young children; a change of water being often nearly or quite as pronounced in its results as a change of air.

In view of this we begin to feel that Webster's definition of "wholesome" as "tending to promote health" may not strictly apply to the case in question; for it seems not unlikely that a shrewd cross-examining lawyer might very readily force the witness to admit that the water was "wholesome" for a part of the community only, namely, those who were acclimated, who had become tolerant to its use.

What has been said regarding change in hardness applies

with equal force to variation in turbidity. In the stranger unaccustomed to its use, a turbid water will often produce a transient form of intestinal disturbance. Shall we therefore declare such a water to be unwholesome? If so, our verdict would to a certainty be opposed by many thousands of people living in our great central basin.

Appreciating the two horns of the dilemma, the writer has adopted this position, namely, assuming the absence of sewerage material and considering the silty turbidity alone, a somewhat turbid water is to be classed as undesirable for many purposes for which a city supply is used, but yet it cannot be rated as unwholesome, for the reason that it is unproductive of disease among the people for whose use it is primarily intended.

The writer, while on the witness-stand, has given substantially the following answer to the question, "What do you mean by a good and wholesome water?" "Such a water should be suited to all forms of domestic use; it should possess no objectionable taste or smell; it should be free from animal, especially human, refuse material; it should be free from vegetable material in a state of active decomposition, distinction being made between such material and those stable extractive matters often found dissolved in brown or peaty wâters, and which experience has shown are not prejudicial to health; finally, it should be free from such amount of suspended material of whatever character as would make it unsightly in appearance and unsuited to the ordinary industrial interests of a community."

Such an answer seems to be about as good as can be framed in reply to so general a question, but, as has been indicated, it is not well to have the words do duty for too general a case. As we have seen, a water suited to the uses of one town might not be best for the interests of another; or perhaps even a portion of a city might, because of its manu-

facturing establishments, desire a different water from that sought after by the residential section of the same community.

Inasmuch as the people usually know whence it is proposed to take the water, would it not be wisdom to place in the contract some form of definite analytical specification, whereby the water, as offered to the consumer, could be held up to the quality established by an accepted local standard.

In conclusion, let a word be said about a matter that has recently awakened no small degree of general interest.

It would seem that the attention of the public has been largely drawn of late to the question of the wholesomeness of distilled water for dietetic purposes, numerous articles having issued from the press under such captions as "Poisonously Pure Water" and the like.

Much uneasiness has been created among those who have substituted the use of distilled water for domestic purposes, in place of some city supply of acknowledged impurity, because of their being told that "distilled water is an active protoplasmic poison, due to its property of extracting salts from animal tissues and causing them to swell up by imbibition."

Stress is, of course, laid upon the increased danger arising from the use of such water by the young, whose tissues are in process of formation.

Surely it is only fair to insist that the burden of statistical proof be borne by those who advance this proposition, and that until such data are furnished we will rest our faith upon such facts as the following:

The Croton water-supply of New York City contains 5.48 grains of solid matter per U. S. gallon, or 1.37 grains per quart.

One quart of water per day for a child would be a fair allowance, considering that milk is also a portion of the diet.

In consideration of the mixed character of human food, and the amount of mineral salt naturally occurring therein and added thereto as condiments, the withdrawal of 1.37 grains of mineral salts per day, by the substitution of distilled water for that drawn from the Croton River, would be a matter of too small importance for consideration.

Finally, let it be remembered that all the vessels of our navy condense their drinking-water by means of the Baird condenser, and the navy medical authorities report most excellent results. Surely the bone and muscle of the "men behind our guns" speak for themselves.

It may be interesting to add that "the Marine battalion, some five or six hundred strong, used distilled water from the ships all the time they were doing shore duty at Guantanamo, Cuba, and they had none of the enteric fever that prevailed so extensively in the Fifth Army Corps."

CHAPTER III.

ARTIFICIAL PURIFICATION OF WATER.

PURE water is better than purified water; that must be accepted as an axiom. But pure water is becoming more and more difficult for many of our towns to secure, so that the best that some of them can hope to obtain is a polluted water which has been efficiently purified by art. It is a question, sometimes, whether it would not be better policy, considering the rapid changes in the density of population, to accept a moderately polluted source and thoroughly purify its water, rather than go to large expense in obtaining a faultless supply which might have to be purified in its turn at some later day.

Further, it must be borne in mind that, outside of any question of wholesomeness, the water which a part of our people are content to use at present will not be considered suitable in a few years to come. The tendency is towards a general demand for a clear and colorless water, and water-purveyors must be prepared to meet it.

Filtration of surface water, before delivering the same for public consumption, is now specifically ordered by the laws of Germany, and rules are laid down for its proper accomplishment. Such legislation is not improbable in this country, thus still further making it the part of wisdom to anticipate the artificial improvement of some waters which are now possibly considered beyond impeachment.

The art of removing suspended material from water by some form of filtration has been known during many ages, although it was not put into extended practice until very recent times; thus the siphoning of liquid from one vessel to another by the capillary action of porous material, such as a strip of cloth, and the consequent separation of the liquid from suspended material, was well known to the ancients and is frequently mentioned.*

The modern methods of filtration claim to do something more and better than merely to strain off the grosser elements of turbidity; and so fully do the people of Europe appear to believe this claim a just one that with them a city water-works without an attendant filter-plant is becoming almost a novelty. The method of purifying water on the large scale which deserves first attention on account of its early use and wide application is that of "slow sand filtration," commonly known also as

THE ENGLISH FILTER-BED SYSTEM.

Briefly described, an English filter-bed is a tight reservoir, suitably underdrained, and containing some five or six feet of stratified filtering material, of progressive degrees of fineness, beginning at the bottom with broken stone or gravel, and ending with an upper layer of fine sand.

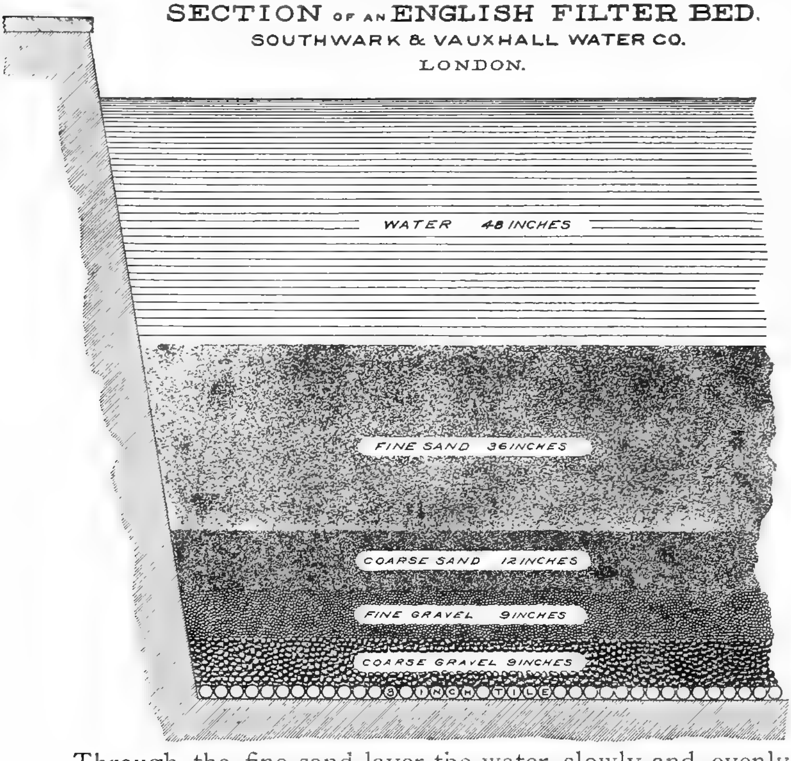
Much diversity exists in the relative thickness of the several layers, some filters being constructed with a very thick upper layer of fine sand, while with others the finest material is put on as a comparatively thin cover. The Dutch filters are especially marked in the thinness of their beds,† a feature by no means to be recommended; for, although much of the actual work of filtration is done by the upper layer of sand,

* Bolton, "Ancient Methods of Filtration." *Pop. Sci. Monthly*, xvi. 495.

† Mr. Halbertsma informs the author that the height of the ground-water level is one reason for the thinness of the beds.

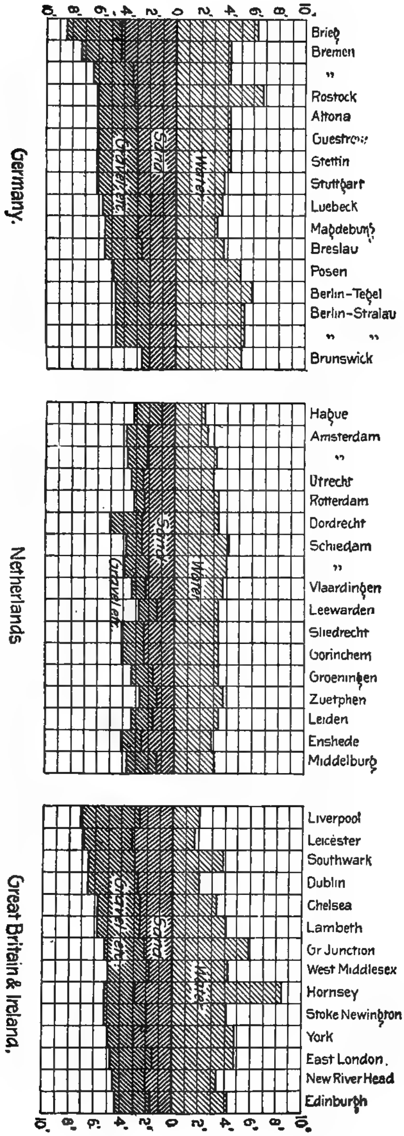
yet if the thickness of the body of the bed be unduly reduced, that portion of the water which is in the act of being delivered will bear too large a ratio to that filling the interstices of the coarser layers; as a result, currents will be established and ruinous channelways be quickly worn in the uppermost stratum.

SECTION OF AN ENGLISH FILTER BED.
SOUTHWARK & VAUXHALL WATER CO.
LONDON.



Through the fine-sand layer the water slowly and evenly passes, leaving the bulk of its suspended impurities upon the surface to form the *Schmutzdecke*, or "dirt cover," of the Germans.

Beyond the mere gradual accumulation of suspended matter strained from the water, this *Schmutzdecke* is in part composed of slimy, jelly-like material, produced through bacterial agency, which serves to entangle and hold bacteria and other suspended substances of all kinds.



COMPOSITION OF VARIOUS FILTER-BEDS. (AFTER HALBERTSMA.)

COMPOSITION OF VARIOUS FILTER-BEDS, IN INCHES.

	Fine Sand.	Coarse Sand.	Fine Gravel.	Medium Gravel.	Coarse Gravel.	Small Stones.	Large Stones.	Total Depth.
Berlin	22	2	6	5	3	4	12	54
Warsaw	24	....	2	....	3	12	11	52
Zurich	32	6	4	....	6	......	......	48
Hague	12	10 (sea-shells)	......	....	10	......	6	38
Hudson, N. Y.	6	18	6	6	6	6	24	72
London: Chelsea	54	....	3 (shells)	39	......	......	......	96
London: Lambeth	36	....	12 (shells)	....	36	......	......	84
London: Southwark and Vauxhall	36	12	9	......	9	......	......	66
London: W. Middlesex	27	12	......	....	27	......	......	66
Poughkeepsie, N. Y.	24	....	......	18	......	6	24	72
Hamburg	40	....	......	24	......	......	......	64
Albany, N. Y.	48	....	$2\frac{1}{2}$	2	6	......	.....	$58\frac{1}{2}$

It must not be thought, however, that the extreme top layer of sand, with its cover of slime, does the entire work, so far as purification is concerned. Each of the sand grains of the body of the bed becomes covered with a sticky coating of the zoöglœa jelly, and they collectively are to be credited with a large share of the results accomplished. This is shown by Reinsch, who has published his observations of the Altona filters. He found the unfiltered water to contain 36,320 microbes per cubic centimetre. After passing the slime layer there yet remained 1876, but after going through the entire depth of sand there were found but 44 per cubic centimetre. Thus the lower layers have uses other than mere regulation of flow.

As will be observed from the table on page 142 a filter recently disturbed by the process of cleaning is lower in efficiency than one which has been for some time in operation. A filter might be properly described as "at its best when at its dirtiest"; and, were it not that it finally becomes almost impervious to water, it would be better not to clean it at all. A new filter is of small use until it "ripens" for work; that

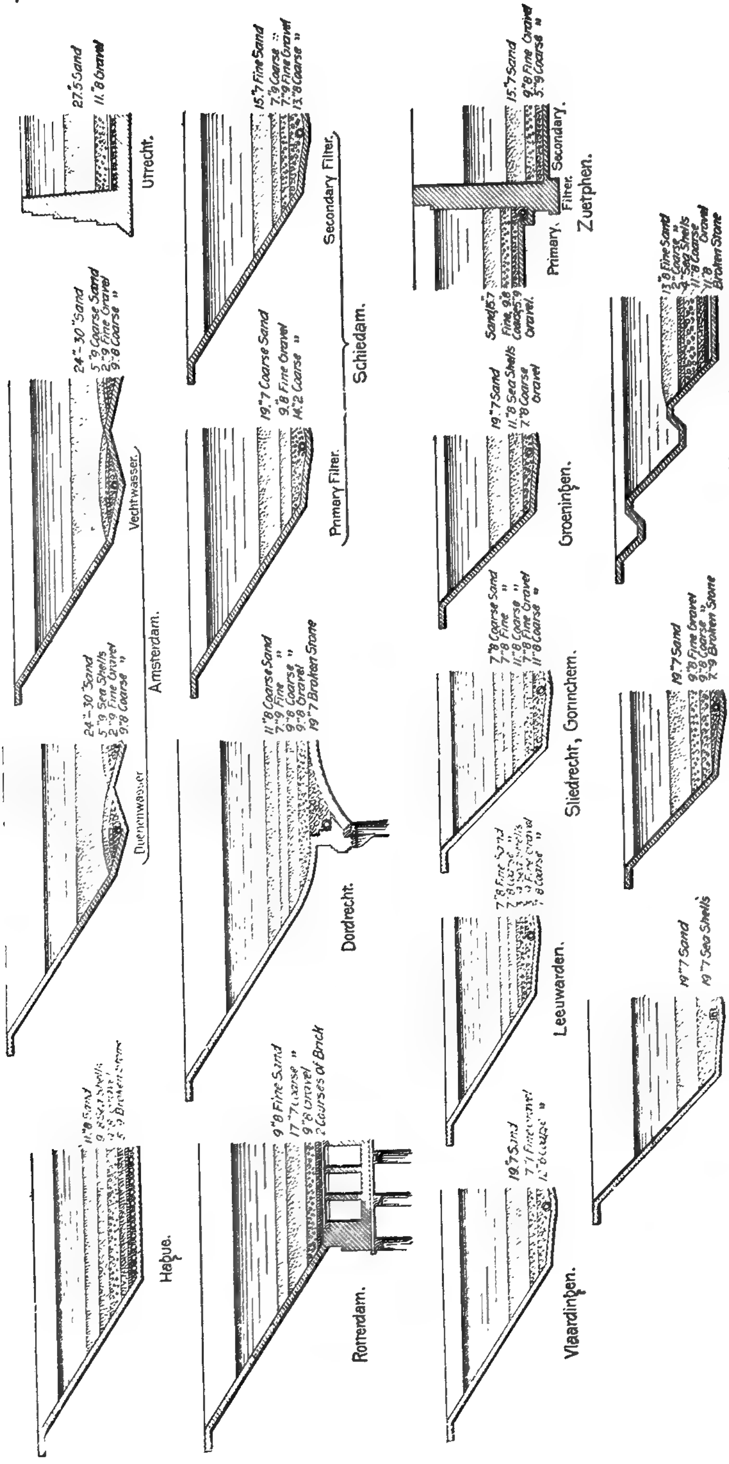
is, until the "nitrifying" organisms have firmly established themselves and the zoöglœa jelly envelops the sand grains. We have here an additional reason for a thick sand layer which will permit more of the filter to rest undisturbed.

For proper working the thickness of the fine-sand layer should be made not less than thirty-six inches, and this depth should not be permitted to greatly decrease, by reason of the successive removals of layers of the upper surface for purposes of cleaning. The German law prohibits the reduction of the fine-sand layer below the limit of twelve inches.

"Perhaps the most interesting fact about the filter-beds is the very remarkable change which has lately come about in the theory, if not in the practice, of filtration. Up till two or three years back a perfectly clean filter-bed was the theoretical desideratum, and the Local Government Board experts had serious fault to find with the condition of the beds on the East London Company's works as elsewhere. The best science of the day seemed clear that a filter-bed could not be too clean; but the practical managers of the London water-works found by experience that it could. They knew as a matter of fact that they could not satisfactorily filter their water through a new or clean bed; whereas they could through the ones that the Local Government Board had found fault with." *

The engineering structures containing these various beds of filtering materials differ from one another in size, in shape, and in method of construction, according as the preference of the designer may dictate or the necessities of the case may demand. In London the result of long experience has been the selection of one acre as the proper superficial area of a filter-bed, and new constructions are carried on with that rule in view. The new Hamburg filters are each 1.89 acres in

* W. J. Dibdin's report to the London County Council, 1896. As showing greater bacterial efficiency of a filter with increase of age see also Report Mass. State Board of Health, 1895. p. 511.



SECTIONS OF DUTCH FILTER-BEDS. (AFTER HALBERTSMA.)

area, and those more recently constructed at Albany, N. Y., are each seven-tenths of an acre. Usually the inner wall-surface is nearly, or quite, vertical, but the Holland filters (see page 104) form a notable exception in this particular, having a slope, at times, of more than one to one.

An objection to an entirely vertical wall is that there is possibility of improperly filtered water passing down between it and the sand. A wall broken into steps affords a better opportunity for a good joint being made with the filtering material. This is shown in the sections of the filters illustrated on page 116.

As to composition, the body of the side walls is as varied as one would expect to find it among reservoirs in general; running from earth embankments with clay puddle cores to structures of pure concrete or even of dressed stone. Such as are constructed of earth are, however, carefully protected on the inside, by suitable paving, from the damaging action of ice and waves.

Some of the filters of the Southwark and Vauxhall Company (London) have a layer of three-inch agricultural drain-pipe, placed side by side with open joints, over the entire bottom, thus securing easy flow to the clear-water reservoir. (See illustration, page 100.)

In the new Albany plant these are replaced by lines of six-inch vitrified pipe, open-jointed, and laid thirteen feet eight inches apart.

A convenient form of hollow-tile underdrain has been invented by L. K. Davis. It is easily understood by reference to the illustration on page 107.

Usually filter-plants are entirely open, but in those localities where the winters are severe it becomes necessary to throw over them a cover, which is commonly of concrete, resting upon columns of the same material.

Thick ice renders it practically impossible to properly clean

a filter by the ordinary methods, and the resulting imperfect purification of the filtrate is often coincident with increase in the death-rate. This was noted in Berlin in the winter of 1889, when an outbreak of typhoid fever followed the deficiency in purifying power of the open filters. That portion of the city supplied with water from the covered filters was not visited by the epidemic.

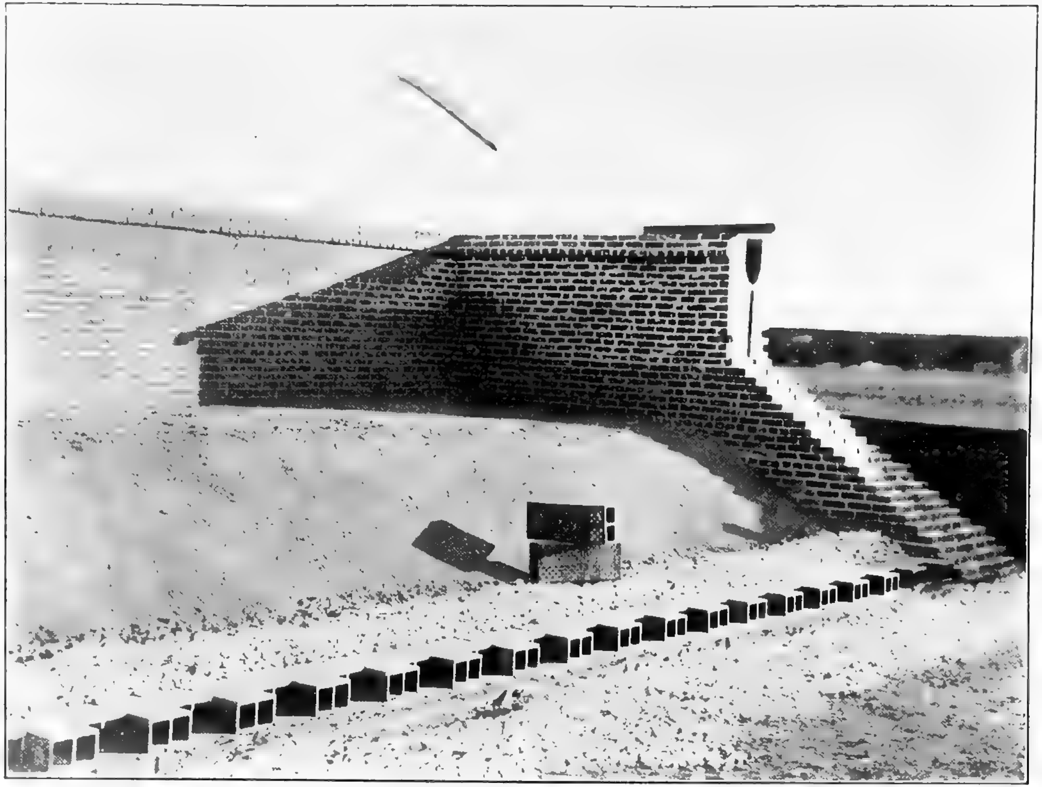
At Hamburg the open filters are cleaned during winter by a device perfected by Mr. E. Mager. The apparatus consists of a float which rests against the under surface of the ice-cake together with a cutting edge attached thereto at a sufficient distance below to pare the *Schmutzdecke* from the sand surface, the dirty sand being received into a pouch following directly behind. The cleaner having been introduced under the ice at one side of the filter, it is pulled over to the opposite side, where its load of dirty sand is dumped by turning the pouch inside out, whereupon it is pulled back again to the first side after having been moved laterally to a distance equal to the width of its swath. The working of the Mager cleaner is said to be satisfactory, but it is very doubtful if it be really so desirable as the more expensive method of insuring winter cleaning by covering the filter.

In England the climate does not demand the construction of the expensive covered filters, and, as a rule, much trouble from ice is not experienced; but even there exceedingly cold weather will at times occur, bringing with it large additions to the bill for expenses of maintenance. A notable winter in this particular was that of 1884, when seventy men were constantly employed in removing ice from the Southwark and Vauxhall beds. (See illustration opposite.)

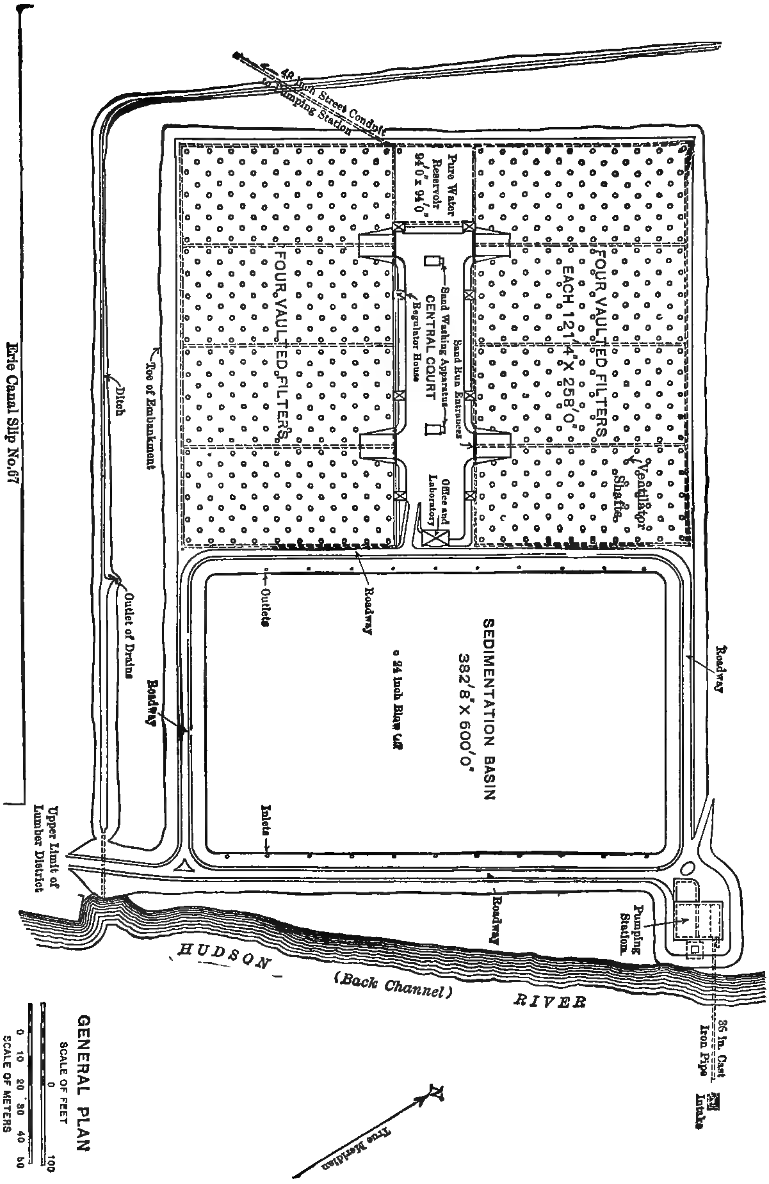
Mr. Allen Hazen, in his excellent work on "Filtration of Public Water-supplies," advocates the covering of filters in all localities where the mean January temperature is below the

REMOVAL OF ICE FROM LONDON FILTER-BEDS.

[*To face page* 106.]



PERFORATED TILE UNDERDRAINS. DEVISED BY L. K. DAVIS.



FILTERS AT ALBANY, N. Y. (HAZEN.)

freezing-point. His recommendation is unquestionably a sound one.

According to his report, the cost of removing ice from open filters at Mount Vernon, N. Y., with a normal January temperature of 31°, has ranged from 0 to 31 cents per 1,000,000 gallons, reckoned on all the water filtered during the year, or rom 0 to $172 per acre of filter surface per annum.

At Poughkeepsie, with a normal January temperature of 24°, the cost of ice removal, including the estimated additional cost of cleaning because of cold, from figures for the last three years, has ranged from 24 to 62 cents, and averaged 43 cents per 1,000,000 gallons of water filtered throughout the year, or to an average of $207 per acre of filter surface per annum.*

An idea of the interior appearance of a covered filter may be obtained from the cut on page 111 showing a filter belonging to the plant at Ashland, Wis.

The engraving on page 113 is from a photograph showing the covered beds at Zurich, Switzerland, in process of construction.

As is well known, the great city of London buys all of its water from eight private companies, and every gallon delivered for use is carefully filtered by the said companies, with the exception of what is derived from deep wells in the chalk. Certain statistics relating to these great plants are given on page 115.†

The cost of constructing a filter-bed upon the general plan described must necessarily greatly vary, in direct ratio, with the local cost of materials, and with the difficulty of the engineering problem involved.

For some well-known plants the cost of construction is given, as follows, exclusive of the price of land:

London.—A bed one acre in filtering area costs from

* See *Engineering News*, Jan. 24, 1901.

† For further information see "The London Water-supply," by Shadwell.

A COVERED FILTER AT ASHLAND, WIS.

COVERED FILTER-BEDS AT ZURICH, SWITZERLAND, UNDER CONSTRUCTION.

Name of Company.	Source of Supply.	Daily Supply in U. S. Gallons.	Number of Filter-beds.	Total Area of Filter-beds, in Acres.	Depth of Filter-materials.
Chelsea........	Thames river	12,727,000	7	6¾	8 ft.
East London. ..	Thames river Lee river Chalk wells Springs	51,495,000	31	29¾	3 ft. 6 in.
Grand Junction.	Thames river	22,391,000	15	17¾	5 ft. 6 in.
Kent..........	Deep Chalk wells	17,126,000	none	....	....
Lambeth.......	Thames river	23,509,000	10	9½	7 ft.
New River.	Chadwell spring Lee river Chalk wells	43,190,000	20	16½	5 ft. 7 in.
Southwark and Vauxhall.....	Thames river	34,080,000	12	14⅓	5 ft. 6 in.
West Middlesex.	Thames river	21,627,000	12	15	5 ft. 6 in.
Total........		226,145,000	107	109¾	....

$24,000 to $39,000, depending on the nature of the ground. Those of the Southwark and Vauxhall plant each cost the latter sum. All these beds are uncovered.

Liverpool.—Same as London.

Zurich.—Covered beds, complete, cost 120 francs per square metre of filtering surface (about $2.25 per square foot, or $98,000 per acre). The uncovered beds, previously in use, cost two thirds of this sum.

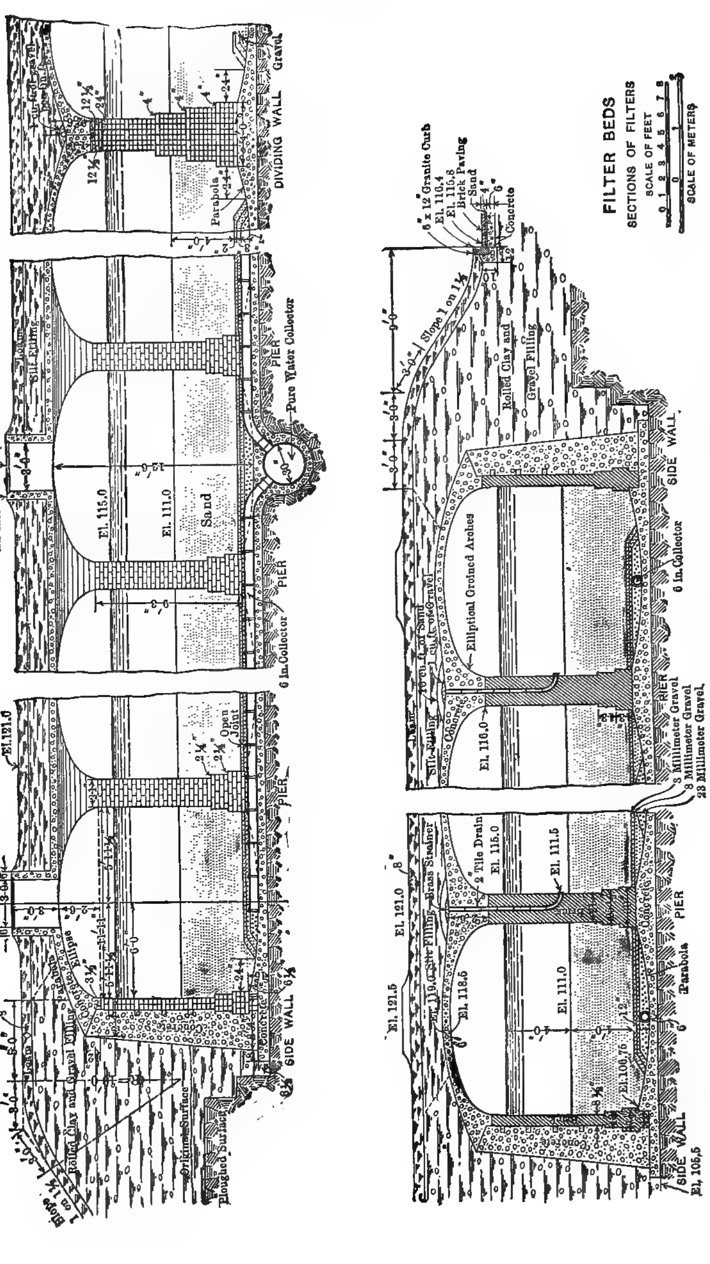
Hamburg.—The new filters are all open, and cost 33 marks per square metre of sand-surface (about 70 cents per square foot, or $30,500 per acre).

Berlin.—The covered filters cost $70,000 per acre, and the open ones about two-thirds that sum. Lindley gives a general estimate for the Continental filters, as follows: Open, $45,000 per acre; covered, $68,000.*

Poughkeepsie, N. Y.—The two (uncovered) beds cost together (in 1870) $75,694, which is at a rate of $112,641 per acre, including price of land.

Hudson, N. Y.—The plant consists of two filter-beds, one

* See also *Engineering News*, Aug. 16, 1894.



ALBANY, N. Y., FILTER-BEDS. (AFTER HAZEN)

of 9071 square feet sand-surface, built in 1874, and one of 23,017 square feet surface, built in 1888. The initial cost of the smaller bed, together with the clear-water reservoir, was $37,450. The newer and larger filter was built for $17,350—the much lower figure for the second filter being accounted for by the partial preparation of its site at the time of the earlier construction.

Ilion, N. Y.—The beds are small, of 3040 square feet each in sand-area. The detailed cost is here given:

170 cu. yds. ashlar masonry	@	$10.00	$1700
332 " " rubble "	"	5.50	1826
240 " " concrete	"	5.00	1200
110 " " filtering gravel	"	1.50	165
551 " " " sand	"	1.50	827
900 " " embankment	"	.32	288
32.3 M brick, laid dry	"	8.00	258
11.8 " " " in cement	"	12.50	148
431 lin. ft. cut coping, 6 × 30 in	"	1.25	539
176 " " " " 4 × 12 in	"	.35	61
247 sq. ft. 6-in. Hudson R. bluestone flagging	"	.40	99
Total			$7111

This is at a rate per acre of $101,900.

These figures do not include sedimentation-basins, which are essential in all cases where the water to be filtered is materially turbid. These basins need not be of great size. Storage sufficient to equal the twenty-four hours' supply is quite enough, for in that time the great bulk of suspended material will settle, and the balance can be economically removed by the filter. Where no settlement is permitted before running a turbid water upon the filter, an unnecessarily rapid clogging of the sand results, with consequent increase in frequency of cleanings.

As illustrating the cost of filter-plants of still more modern

type, the following figures are quoted from reports on recent constructions:

Ashland, Wis.—The beds are three in number; they are covered and of one sixth of an acre each. The complete cost was at the rate of $70,000 per acre.*

Albany, N. Y.—The filters are eight in number, of concrete, with vaulted covers, also of concrete. Miscellaneous data concerning these beds will be found on page 131.

An approximate idea of the cost of filter-beds in general may be obtained from the estimates given by Mr. Edmund B. Weston in a paper in the *Engineering News* of October 7, 1897. The cost of sand filtration at an average rate of 2,000,000 and a maximum rate of 2,500,000 gallons per day, under different conditions, is given by him as follows:

Filter-beds covered with masonry vaulting.

Cost per acre of filter-bed	$70,000.00
Cost of construction per 1,000,000 gallons capacity per twenty-four hours	35,000.00
Total cost of filtering 1,000,000 gallons, including expense of operating, interest, deterioration, etc.	7.57

Filter-beds covered with a wooden roof.

Cost per acre of filter-bed	$43,813.00
Cost of construction per 1,000,000 gallons capacity per twenty-four hours	21,906.00
Total cost of filtering 1,000,000 gallons as above	6.85

Filter-beds not covered.

Cost per acre of filter-bed	$38,829.00
Cost of construction per 1,000,000 gallons capacity per twenty-four hours	19,415.00
Total cost of filtering 1,000,000 gallons as above	6.48

* *J. N. E. Water-works Asso.*, xi. 314.

Filter-beds not covered.

Cost per acre of filter-bed	$31,063.00
Cost of construction per 1,000,000 gallons capacity per twenty-four hours	15,532.00
Total cost of filtering 1,000,000 gallons as above	5.09

The first three estimates are intended for filter-plants that could be located where the mean temperature of the coldest month of the year is below the freezing-point. The third estimate takes into consideration a reserve area to compensate for ice forming over the filter-beds. The fourth and last estimate is intended for a filter-plant that could be located where the mean temperature of the coldest month of the year is above the freezing-point. None of the estimates include the cost of sedimentation-basins.

In Mr. Hazen's opinion covered filter-beds should be roughly estimated as costing $15,000 per acre more than those which are open.*

The Engineer Commission of Cincinnati made the following estimate of cost for filters for that city:

FILTERS AND CLEAR WELL.

11 filters, 220×400×11 feet; clear well, 148×1180×18 feet.

Estimate for one filter.

26,372.5 cubic yards excavation	@	$0.30	$7,911.75
4,489.6 " " puddle	"	1.00	4,489.60
1,664.4 " " concrete	"	5.00	8,322.00
1,834 " " masonry	"	7.50	13,755.00
3,520 cubic feet coping	"	1.50	5,280.00
66,528 brick	"	12.00	798.33
7,480 lineal feet small vitrified drains	"	.12	897.60
666.66 cubic feet stone slabs	"	1.50	1,000.00
Five regulating-valves	"	300.00	1,500.00

* *Engineering News*, Jan. 24, 1901.

Pipes, specials, and valves........	@.....		$6,196.74
8,148.15 cubic yards fine sand.	"	$1.00	8,148.15
4,074.07 " " coarse sand.......	"	1.00	4,074.07
1,629.63 " " small gravel...	"	1.00	1,629.63
4,074.07 " " coarse gravel....	"	1.00	4,074.07
Total....................			$68,076.94

Clear well.

105,956 cubic yards excavation......	@	$0.40	$42,382.40
14,439 " " puddle..........	"	1.00	14,439.00
3,704 " " concrete.........	"	5.00	18,520.00
5,405 " " masonry........	"	7.50	40,537.50
6,660 cubic feet coping.	"	1.50	9,990.00
2,664 lineal feet iron fencing.......	"	2.00	5,328.00
Pipes, specials, and valves...................			31,500.00
Total..........................			$162,696.90
Eleven filters..........	@	$68,076.94	$748,846.34
5,206 cubic yards conc. pavement	"	5.00	26,030.00
4,450.4 " " gravel pavement	"	1.00	4,450.40
45.06 acres of land..........	"	150.00	6,759.00
Total..........................			$948,782.64

Cost per acre of filtering area, $43,126.50.

Daily capacity of each filter, 6,000,000 gallons.

When a battery of several filters is under construction, it is very desirable that the separate beds be so arranged as to permit of the flow being watched from each one individually, otherwise the general filtrate might be damaged by the poor working of a single member of the group, and no means would exist of detecting and remedying the evil. A table illustrating this point is given on page 142.

An important departure from the established type of open filter-beds was made at Lawrence, Mass., after a design, furnished by Mr. H. F. Mills, which is intended to take advan-

tage of the benefits to be derived from intermittent filtration. The area of the bed in question is 2½ acres, its daily capacity is 5,000,000 U. S. gallons, and its cost has been about $67,000.

In this plant, both the bottom of the containing reservoir and the surface of the filtering-sand have transverse ridges, notably higher than the depressions between them; the ridges of the bottom corresponding to the depressions of the sand-surface. The water is admitted along the depressions in the sand-surface, in concrete gutters laid for a short distance thereon, and gradually overflows the surface until the sand-ridges are covered by a foot.

The underdrains are of tile pipe, laid with open joints, and covered with graded coarse materials. The filtered water is pumped to the consumers, and the running of the pumps and the opening or closing of the inlet are so arranged as to permit of the filtering-sand being entirely drained once in each twenty-four hours, whereby thorough aeration is secured. Excellent as are the results reported from the Lawrence filter, they are no better than those to be obtained by continuous filtration.

For the purification of sewage, intermittency of filter action is essential, for the reason that enough oxygen is not present to supply the large amount of organic material that is there to be oxidized. Were the stream of sewage applied continuously, nitrification could not be established and purification would quickly cease. With water the case is otherwise. Enough oxygen is present in solution to furnish all the needs of the nitrifying organism, and therefore the additional cost that must follow the erection and maintenance of an intermittent filter is not warranted.

The relative efficiency of the two forms of filter under the differing conditions named is shown in the following table: *

* Report Mass. State Board Health, 1896, pp. 522, 523, 538, 544.

	Bacteria per c.c. in Raw Water.	Per Cent Oxygen Dissolved in Filtrate.	Efficiency of Filter.
		Per cent of saturation.	Per cent.
1. Intermittent	9,400	83	98.59
2. Continuous	9,400	67	99.17
3. Intermittent	186,000	43	91.80
4. Continuous	186,000	8.7	76.89

Nos. 1 and 2 are with Merrimack River water, while Nos. 3 and 4 are with the same water to which additional pollution in the shape of sewage has been added and filtration begun after some hours' standing.

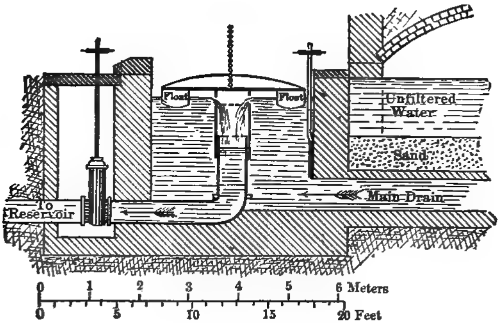
Mr. Mills called the writer's attention to an interesting fact connected with the management of the Lawrence filter. It seems that, in aerating the sand-bed, the practice for some years had been to draw down the water so low that its level fell below the underdrains. Air was therefore commonly present about such drains. In consequence ferrous salts became oxidized to insoluble oxides and *crenothrix* developed in the pipe-joints. Passage of water was finally stopped by the accumulation of gelatinous iron deposit, and the sections of the bed affected had to be entirely dug out and cleaned. Of course the remedy for the future was to avoid drawing down the water to so low a level.

The depths of water permitted upon filters of the English type are almost as various as the compositions of the beds themselves.

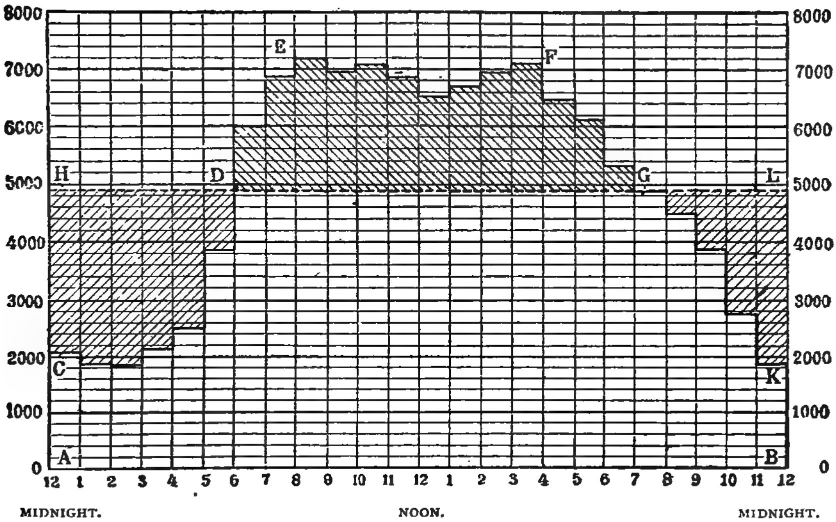
Three and a half to four feet of water may be taken as the depth most commonly in use, and it is important that this depth, when once determined upon, should be maintained a constant. At Hudson, N. Y., the head of water varies exceedingly, running from a few inches to over six feet. Such inequality as must result in the rate of filtration cannot but cause wide differences in the purity of the filtrate.

With the more modern filters the rate of delivery of filtered

water is independent of the depth of water on the sand, being controlled by an effluent regulator, an excellent form of which was devised by Lindley for the Warsaw works and is shown



EFFLUENT REGULATOR. (LINDLEY.)



VARIATION IN HOURLY CONSUMPTION OF WATER AT BERLIN, STATED IN CUBIC METRES. (FRANKEL.)

herewith. The outflow takes place through the horizontal slits under a head which is maintained constant by means of the

floats attached to the upper end of the cylinder, which telescopes the fixed outlet.

By use of some such device as Lindley's, associated with a simple overflow-pipe to correct errors from too deep flooding of the bed, constancy in rate of filtration can be assured, a point of material importance in the proper management of a filter.

The following data * show the ill effects of violent changes in the rate of filtration:

Rate, in Million Gallons per Acre per Day.	Bacteria per c.c. in Effluent.	
	Before Change.	After Change.
7 to 15	131	185
6 " 16	87	95
6 " 12	96	167
5 " 6	35	60
5 " $6\frac{1}{2}$	132	490
5 " $7\frac{1}{2}$	60	92
5 " $7\frac{1}{2}$	55	81

Of course, inasmuch as no city uses a constant quantity of water during each hour of the twenty-four, it becomes necessary, in order to permit the filtration to go on with regularity, to provide a pure-water reservoir large enough to store the filtered water accumulating during the hours of small demand, and from which may be furnished the supply required during the period when the rate of filtration is not equal to that of consumption.

To show how the hourly consumption may vary in a large city, the diagram on page 123, taken from a recent report, indicates the variation for the city of Berlin.

It should be observed that the hourly consumption varies less in a large than in a small city; therefore the former can

* Rep. Mass. Board of Health, 1895, p. 516.

more properly erect a relatively small clear-water reservoir. One recently proposed for Philadelphia is designed to hold half a day's supply.

Considerable difference is noted as to the amounts of water permitted to pass the sand during twenty-four hours, as is shown by the table given below, representing the delivery of some well-known beds:

RATES OF FILTRATION.

	U. S. Gallons per Acre per Day.	U. S. Gallons per Square Foot per Day.	Vertical Inches per Hour.
Albany, N. Y.	3,000,000	69	4.6
Berlin (Tegel).	3,179,880	73½	5.9
Zurich	7,492,000 to 10,672,000	172 to 245	11.5 to 16.4
Stuttgart.	2,134,440	49	3.3
Altona.	2,613,525	60	4.0
Liverpool.	2,613,525	60	4.0
London: Chelsea.	2,178,000	50	3.3
London: East London.	1,655,280	38	2.5
London: Grand Junction.	2,570,000	59	4.0
London: Lambeth.	2,700,700	62	4.1
London: New River.	2,570,000	59	4.0
London: Southwark	1,873,000	43	2.7
London: West Middlesex.	1,655,280	38	2.5

The best practice places two and a half to three million U. S. gallons per acre per day, or four to four and a half vertical inches per hour, as the limit, beyond which the rate should not be pushed.

By direction of the Imperial Board of Health the maximum rate of filtration has been fixed in Germany at four vertical inches per hour.

The necessity of limiting the daily delivery of a filter to the above quantity is questioned by the Massachusetts Board of Health. They find that while such a rate is proper for new filters, a higher delivery may be assigned to those which have been in service during a long period, "owing apparently to a

more extended accumulation of gelatinous films within the main body of the filtering material." *

In consequence of experiments conducted by himself, Kümmel of Altona, although he accepts the *dictum* of the board of health, considers the question of the proper rate of filtration as not entirely closed.

When dealing with the question of the rate of filtration, the following table prepared by Mr. G. W. Fuller will be found convenient:

EQUIVALENTS OF VARIOUS MEASURES OF RATE OF FILTRATION.

	Million U.S. Gals. per Acre per 24 hrs.	U.S Gals per sq. foot per hour.	Cubic ft. per sq. yard per hour.	Vertical Velocity in inches per hour.
1 million U. S. gals. per acre per 24 hrs..	1.	.96	1.15	1.53
1 U. S. gal. per square foot per hour....	1.045	1.	1.2	1.6
1 cubic foot per square yard per hour....	.869	.83	1	1.33
1 linear inch in vertical velocity per hour	.652	.62	.75	1

For the purpose of cleaning a filter of the English type, a gang of laborers is set to work upon the drained bed, and by means of sharp shovels they pare off the upper half-inch of sand and pile the same into small heaps, whence it is removed by wheelbarrows to the sand-washer. This thin upper layer of sand (the *Schmutzdecke* of the Germans) contains the greater bulk of the material separated from the water by filtration. It is quite compact, and is so distinctly separated from the sand below as to make the work of its removal very simple. It is liable to be quite membranous in character, and its imperviousness to water is what causes the filter to become "dead" and require cleaning.

The frequency with which filters have to be cleaned

* Rep. Mass. Board Health, 1894, p. 609.

depends upon the condition of the water being filtered, and, for the same water, this condition will vary greatly with the time of year and character of the season. Thus the London beds experience difficulty from March to July, becoming during those months quickly clogged with fish-spawn, which arrests filtration, and at times renders it necessary to remove the water from the top of the filter before the obstruction can be taken off with rake and shovel.

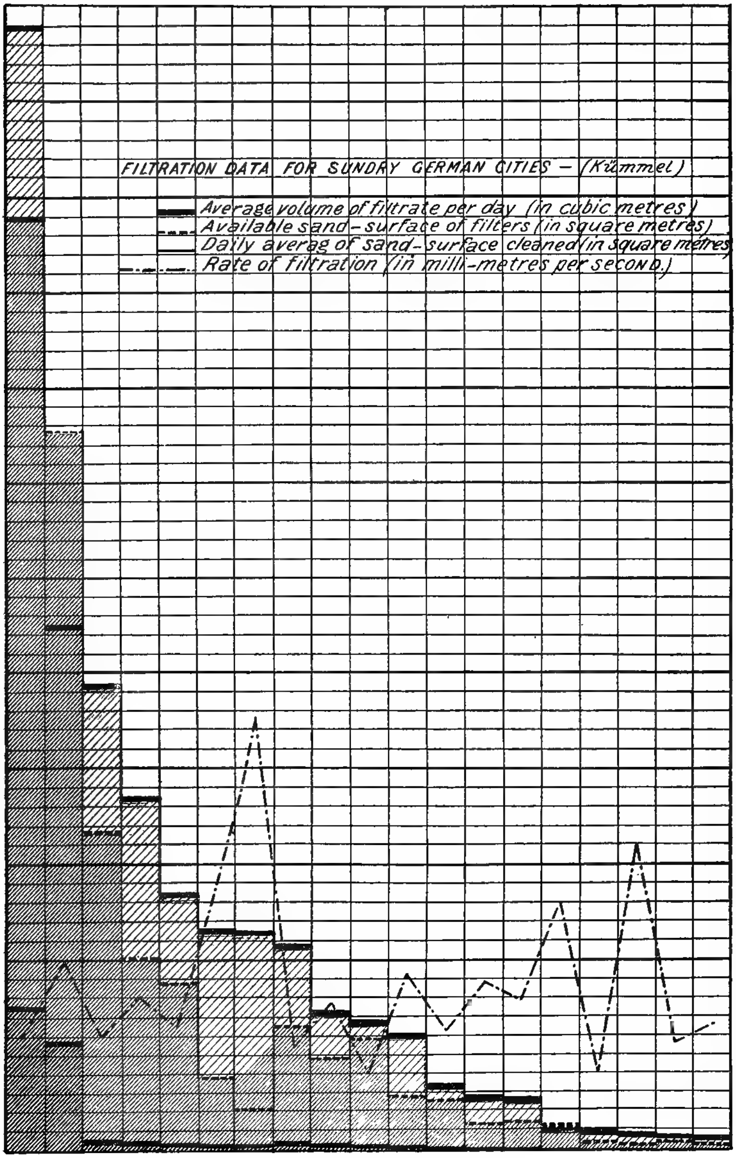
From July until October another difficulty, scarcely less serious, is the growth of vegetation, which begins upon the bottom.

Roughly stated, it may be said that a filter becomes "dead" (i.e., nearly impervious to water), and consequently demands cleaning, once every three or four weeks in summer and about half as frequently in winter; but it is not possible to lay down hard-and-fast general rules applicable to all filters. So many variable quantities enter the consideration that the question of proper time for scraping must be answered for each filter by itself, basing decision upon intelligent observation of the rate of flow, loss of head, and the obvious general efficiency.

The average interval between scrapings at Albany is 25.1 days.

It is not customary nor desirable to have the newly scraped filter remain out of service until the sand removed is washed and returned to its place; for the fine sand-layer should be thick enough to permit of a number of successive scrapings without impairment of its efficiency; therefore the sand taken off during a series of parings is all washed and returned at one time.

At Albany the sand-layer, which is 48 inches thick, has been reduced as much as 17 inches by successive parings before the normal thickness was restored by replacing the cleaned sand.


FILTRATION DATA FOR SUNDRY GERMAN CITIES — (Kümmel)
Average volume of filtrate per day (in cubic metres)
Available sand-surface of filters (in square metres)
Daily averag of sand-surface cleaned (in square metres)
Rate of filtration (in milli-metres per second.)

Considerable variation is found among the methods employed to accomplish the cleaning of the dirty sand—from the refined systems in use at Liverpool and Albany to the comparatively simple and less efficient process employed by some of the water companies at London. At the latter place washing is undertaken by the use of a simple hose played upon the sand-heap, suitable inclined drains carrying off the wash-water. At Liverpool and other places rotary sand-washers scour and clean the sand with great thoroughness, and at Albany the same good result is obtained by an ejector apparatus, which, by the way, requires about 50 pounds water-pressure for its proper operation. Upon an average it takes about 12½ cubic yards of water to wash one cubic yard of sand by this apparatus.

At Hudson, N. Y., the new filter was built with an arrangement by which the water from the pumping-engines could be delivered at the bottom of the bed, if so desired, and forced upward through the filtering materials. It was hoped to thus float off the "dirt-cover" from the upper sand, and thereby save labor in cleaning.

After a thorough trial the method was pronounced a failure, and abandoned. But even had the dirt-layer been successfully floated off, this mode of procedure would have been a very questionable one; for the water introduced into the lower levels of the bed by the reversed current was unfiltered, and must shortly have polluted the filtering materials; and even had the water been pure, the delivery of it, direct from the force-main, would certainly have tended to the formation of channelways in the sand, a result very fatal to good filtration.

The cost of cleaning a filter and washing and replacing the removed sand depends upon the plan adopted for the work, the design of the filter, and the local price of labor.

The following figures give the cost for sundry items in different places:

London (Southwark and Vauxhall) (open filters).—To scrape and wheel dirty sand to washer requires 400 man-hours per acre of sand-surface. Labor, 9½ cents per hour. Ice is not usually removed, but is raked into ridges. The cost of this is roughly found to be about three times that of the ordinary cleaning.

London (New River) (open filters).—To scrape one acre and wheel out dirty sand requires 144 man-hours. Labor, 9.3 cents per hour.

Liverpool (open filters). Cost of scraping and wheeling is $12.50 to $25 per acre, depending upon length of barrowing. Ice is occasionally broken up where it touches the walls, but is not removed. Labor, 9.1 cents per hour. Cost of cleaning per million U. S. gallons filtered, $1.14.

Schiedam (open filters). Scraping and wheeling out dirty sand requires 174 man-hours per acre. Labor, 6 cents per hour. In Holland the sand is usually not washed, it being cheaper to obtain fresh sand for refilling.

Rotterdam (open filters).—The mean cost for filter management, including cleaning, washing new sand, and trouble with ice, has been during ten years $1.53 per million U. S. gallons water filtered.

Poughkeepsie, N. Y. (open filters).—Labor, 17 cents per hour.

Scraping one acre and removing dirty sand...	174 man-hours
Washing sand so removed.................	27 " "
Replacing such washed sand...............	101 " "
Hence cleaning per acre.................	302 man-hours

Square feet scraped per man-hour, 250.

Cubic yards washed " " " .33 to .44.

" " replaced " " " .66.

Cost of cleaning per acre, $51.34.

CLEANING LONDON FILTER-BEDS.

[*To face page* 130.]

Cost of maintenance and operation per million U. S. gallons filtered (average for twenty years), $2.99.

*Ashland, Wis.** (covered filters).—Labor, $1.50 per day. The dirty sand is not washed, but is replaced by new. The time required for cleaning one of the beds of one sixth of an acre is half a day, and the total cost thereof about $8.50. This is at the rate of about $50 per acre for cleaning, not including replenishing. The entire cost of cleaning and maintenance, including that of restoring the sand removed, for one yer, is as follow s:

Number of cleanings, 29.	
Cost of 29 cleanings, at $8.50	$246.50
Reduction in depth of sand-beds is about 9 inches, to replenish which requires 610 cu. yds., at $1 placed	610.00
Making cost of cleaning and replenishing	$856.50
Add for contingencies and superintendence, 5 per cent	42.87
Total cost	$899.37
Cost per million gallons filtered, not including interest on plant	2.26

The average rate of filtration per acre per day was 2,180,064 gallons.

Albany, N. Y. (covered beds).—The following information concerning the Albany filters was furnished the writer by Superintendent George I. Bailey:

Complete filter-plant put in operation September, 1899.

Number of filter-beds, 8.

Dimensions of each filter, 258 feet long × 121.33 feet wide.

Filter area of each bed, 0.7 acre.

Inches of gravel in filter-bed, about 14.

* For detailed cost see *J. N. E. Water-works Asso.*, xi. 316, and *Engineering News*, xxxviii. 338.

Inches of sand in filter-bed, 48.

Effective size of sand, 0.31 millimetre.

Uniformity coefficient of sand, 2.3.

Capacity of clear-water basin, 600,000 U. S. gallons.

Dimensions of clear-water basin, 94 feet wide × 94 feet long.

Elevation of sedimentation-basin above river, 18 feet.

Dimensions of sedimentation-basin, 382.7 feet wide × 600 feet long.

Gallons supply to filter level in sedimentation-basin, 5,700,000.

Number of centrifugal pumps, 2.

Capacity of each per twenty-four hours, 16,000,000 U. S. gallons.

Diameter of pure-water conduit to city pumping-station, 48-inch (steel riveted pipe).

Depth of water on filter-bed, 4 feet.

Total cost of construction of filter-beds, including piping and laboratory, $225,000.

Cost of construction per acre net filtering area, $45,600.

Cost of sedimentation-basin, $60,000.

Cost of construction, pure-water reservoir, $9000.

Cost of land, $8290.

Cost of pumping-station and intake, $49,745.

Cost of pure-water conduit and connections, $86,638.

Cost of engineering and contingencies, $31,000.

Total cost of plant, $499,890.

Operation:

- Average rate of filtration per acre per day, 2,698,000 gallons.
- Average depth of sand removed at each scraping, 0.62 inch.
- Average interval between scrapings, 25.1 days.

Average gallons per acre between scrapings, 67,730,000.

Permissible loss of head, 4 feet.

Normal turbidity of river-water, .035 to .04 (reciprocal scale).

Average turbidity of river-water, .08 (reciprocal scale).

Normal turbidity removed, complete.

Normal color removed, 20 per cent.

Time required to scrape one acre of sand-surface, 67 hours.

Cost of maintenance and operation per million gallons filtered:

Price of labor per hour	0.18\frac{3}{4}$
Scraping beds	.24
Wheeling out scrapings (round-trip distance, 500 feet)	.45
Washing sand, including wash-water	.42
Replacing sand on beds (round-trip distance, 600 feet)	.32
Incidentals and lost time	.23
Total cost	$1.66

Lawrence, Mass. (special open filter).—Cost per million gallons filtered during 1897:

Scraping and replacing sand	$2.55
Removing ice	2.03
Washing sand	1.14
Hauling sand	2.38
General maintenance	1.04
Total per million gallons	$9.14

Hamburg, Germany.—The cost of running the new filters is twenty-one marks (about $5) per million U. S. gallons fil-

tered water. This sum, however, includes pumping and pump repairs.

Before consenting to the large outlay of funds required for filtration by the English filter-bed system, the taxpayer very properly asks what efficiency may be looked for from such a construction.

The best answer to this question is to quote the recorded duties of some existing plants.

Thus the official report for London for the month of August, 1901, stands:

	Bacteria per c.c.
New River, unfiltered (mean of 26 samples)	284
New River, filtered (mean of 130 samples)	13
Thames, unfiltered (mean of 26 samples)	1646
Thames, filtered (mean of 299 samples from eight different companies)	22

Hence efficiencies measured by removal of bacteria were:

New River	95.4 per cent
Thames companies	98.6 "

The London filters have shown better results than the above, and we are securing higher efficiencies in America than those quoted.

Thus the experimental filter erected at Pittsburg, Pa., for the purpose of determining the best method of purifying the Allegheny River water gave an average efficiency of 99 per cent, with a maximum of 99.96 per cent and a minimum (during the winter weather) of 97 per cent.

The efficiency of the new Albany plant from September, 1899, to December, 1900, will be found on page 135.

In connection with the results there given it is well worthy of note that the efficiency of the beds increased after the first

few weeks of use. In other words, a new filter cannot be expected to render such good service as one which has become "ripened."

Month.	Bacterial Count.						Average Removed, Per Cent.
	Raw Water.			Pure Water.			
	Highest.	Lowest.	Average.	Highest.	Lowest.	Average.	
1899, September	29,300	10,200	16,800	800	244	343	97.6
October...	21,000	2,500	10,700	267	37	142	98.6
November.	21,000	3,400	9,200	115	35	71	99.2
December.	80,200	16,800	45,800	450	96	213	99.4
1900 January...	124,000	37,500	66,300	3,500	225	1,232	98.3
February..	230,000	69,000	119,800	2,925	160	938	99.2
March	120,000	17,000	44,700	732	200	426	98.8
April.....	49,000	4,500	26,000	165	54	80	99.6
May	6,400	1,400	2,600	74	20	35	98.6
June......	6,700	1,400	3,100	85	25	45	98.4
July	12,000	1,200	3,500	45	19	32	98.6
August....	7,800	1,100	3,400	30	18	23	99.1
September	8,400	1,300	5,000	35	18	24	99.4
October...	8,000	2,100	18,500	40	19	25	99.4
November.	55,000	2,250	47,600	260	35	93	99.3
December.	75,000	16,000	63,700	320	125	232	99.5

No better illustration can be given of what sand-filtration is capable of accomplishing than is presented by the record of the ten filters at Altona, Germany, during the month of February, 1893. The average number of germs per cubic centimetre in the raw Elbe water for that month was 28,667, whilst the corresponding average for the filtered water was only 90; showing a removal, by filtration, of 99.69 per cent of germs of all kinds.

What this removal meant for the city of Altona during the cholera outbreak at Hamburg in 1892 has already been touched upon (page 55), and may be epitomized in a single word—"safety."

Col. A. M. Miller, U.S.A., lays particular stress upon the necessity for a low number of germs per cubic centimetre yet remaining after filtration, as well as a high percentage of removal representing the filter's efficiency.

This seems a just view, for a high percentage of removal might yet permit of an entirely undesirable number of bacteria in the filtrate when operating upon a raw water of high pollution.

Both high percentage of removal and a low residual number of germs should be required, and it would be also wise to demand the absence or practical absence of the *Bacillus coli communis.*

Let it be understood, however, that in the interest of fairness it would be an error to compare the efficiency percentage of two filters which operated upon raw waters of widely different degrees of pollution.

Given a raw water containing a large number of bacteria per cubic centimetre, it is a relatively easy matter to show a high percentage of efficiency in a filter used to purify the same; while on the other hand it is difficult to secure a high percentage of germ removal, even with the best of management, if the "count" in the raw water be very low.

If the *Bacillus coli communis* be absent in a filtered water, it is safe to assume the absence of the *Bacillus typhosis*. The occasional presence of a few of the former is not greatly objectionable, for the reasons that it is much more numerous in the raw water than the *Bacillus typhosis;* it has a greater longevity under adverse conditions such as are furnished by water-carriage; and, further, it has been experimentally shown that, of the two forms, the *Bacillus typhosis* is the more readily removed by filtration; * not because of material difference in size, but rather on account of its relatively small power to resist the adverse conditions present in the filter.

The efficiency of an experimental filter at the Massachusetts experiment station is here given: †

* See Report Mass. State Board of Health, 1898, p. 487.

† Ibid., p. 498.

MONTHLY AVERAGES PER CUBIC CENTIMETRE.

1898	Raw Water.		Filtered Water.	
	Total Bacteria.	*B. coli communis.*	Total Bacteria.	Single instances when single *B. coli* were found. (More than one germ was never found.)
January	4442	35	31	8
February	5387	32	20	3
March	3108	14	15	1
April	1964	24	14	2
May	3300	26	18	2
June	7484	42	23	0
July	8224	93	15	0
August	5829	123	14	3
September	9836	172	19	2
October	9196	51	49	4
November	4132	44	22	3
December	4554	30	23	4
Average	5621	57	24	

The filter at Lawrence, Mass., belongs to a class of its own, and, by its intermittent action, seeks to derive a large fraction of its efficiency from a thorough development of the nitrifying organism within the bed, and thus burn the nitrogenous organic materials to nitrates. It has a high efficiency, about 99 per cent, but does no better work than can be secured from a filter of the continuous type.

How Lawrence has benefited by the action of this filter may be judged from the fact "that the mortality from typhoid fever has, during the use of the filter, been reduced to 40 per cent of the former mortality, and that the cases forming nearly one half of this 40 per cent are undoubtedly due to the continued use of unfiltered river-water drawn from the canals."

In this connection the following two tables are interesting.

The new sand-filters at Hamburg were started in May, 1893. Their influence upon the typhoid-fever death-rate is shown as follows:

1890	28 per 100,000 inhabitants
1891	23 " " "

1892............	34 per 100,000 inhabitants
1893............	18 " " "
1894............	6 " " "
1895............	9 " " "

TYPHOID-FEVER DEATH-RECORDS AT ALBANY, N. Y., BEFORE AND AFTER INTRODUCTION OF FILTERED WATER.*

Months.	Water.			
	Unfiltered.		Filtered.	
	Average for 9 years.	1899.	1899.	1900.
January	11	14	....	3
February	10	12	....	1
March	12	14	....	3
April	8	13	....	5
May	4	3	....	4
June	4	9	....	1
July	4	2	....	3
August	8	4	....	6
September	6	....	2	4
October	4	....	4	5
November	6	....	0	4
December	8	....	1	0
Total	85	71	7†	39‡

* Portions of the supply are still from gravity sources, unfiltered.
† Physicians report one case contracted out of city.
‡ Physicians report six cases contracted out of city.

The thoroughness with which nitrification, and consequent purification, can be accomplished, by filtration through shallow beds of even very coarse material, has been perfectly worked out and demonstrated by the admirable investigations of the Massachusetts experiment station, and one important point elucidated is that a small amount of oxygen (1 to 3 per cent) in the air of the filter is as effective as a larger quantity.

It would be impossible here to devote space to a proper recounting of the valuable work of the Massachusetts State Board of Health upon the subject of filtration, but a few words from a report of G. W. Fuller, one of the bacteriologists then

in charge, will give an idea of the efficiency with which bacteria may be removed by five feet of filtering material intelligently managed:

"The actual efficiency of the filters was tested by the application of typhoid-fever germs and other important kinds of bacteria, and observations on their passage through the filters. The pure cultures of the micro-organisms were grown in dilute bouillon solutions. Twenty-five or fifty cubic centimetres of these solutions, containing millions of germs, were applied to the filters in a small quantity of water, and the effluent was examined at frequent intervals for several days. Fifty-five such experiments were made during the first five months of 1892, with these average results:

Number of filters tested.................	11
Number of experiments with typhoid-fever germs..	22
Number of experiments with *B. prodigiosus*.......	19
Number of experiments with *B. coli communis*.....	14
Average rate of filtration, gallons per acre, daily...	1,350,000
Number of bacterial determinations.............	914
Average number of bacteria per cubic centimetre applied............................	104,200
Per cent removed..............................	99.48

[The extreme limits in the rates of filtration in the several experiments were 280,000 and 2,600,000 gallons per acre, daily.]

"These experiments were very severe tests upon the efficiency of the filters in removing bacteria, because the number applied was probably greater than would occur in practice, and furthermore the organic matter introduced with the bacteria served them as a food material. The experiments made during the latter portion of the year are much fairer, because the bacteria were applied in small and long-continued doses at frequent intervals, and the food material applied with them did

not increase the organic matter in the river-water beyond the limits of variation observed from time to time in the amount originally present. The species of bacteria used was *B. prodigiosus*, on account of its easy and reliable differentiation, its similarity to the typhoid-fever germ in its mode of life in Merrimac River water, and the fact that it has never been found native in this country. In the following table are summarized the average results of daily experiments from September 16 to December 31, 1892:

Number of filters experimented upon..........	11
Number of bacterial determinations..............	2,372
Rate of filtration, gallons per acre, daily........	1,700,000
Average number of *B. prodigiosus* per cubic centimetre applied..........................	5,700
Per cent removed..........................	99.87."

As a further interesting illustration of the purifying powers of sand-filters, the following comparisons are made between the

	In Parts per million.					Bacteria per Cubic Centimetre.
	Free Ammonia.	Albuminoid Ammonia.	Chlorine.	Nitrogen as Nitrates.	Nitrogen as Nitrites.	
Tank 1, for two months...........	.313	.272	48.3	17.8	.008	549
Well-water, Atlantic Street.........	1.410	.155	80.8	23.7	.024	4370
Tank 13, for six months...........	.011	.105	72.8	12.5	.004	76
Well-water, Hampshire Street......	.078	.118	75.1	20.0	.007	128
Tank 6, for three months..........	.036	.104	49.8	16.6	.002	678
Well-water, Andover Street........	.184	.046	27.9	15.0	.018	46
Tank 4, for two months...........	.025	.108	37.2	7.5	.002	20
Well-water, Salem Street..........	.070	.086	76.7	14.0	.014	447
Tank 2, for four months...........	.007	.065	39.8	7.1	.000	17
Well-water, Lowell Street..........	.012	.070	71.1	21.0	.000	27
Tank 7, eight months..............	.014	.063	40.4	10.6	.000	7
Well-water, Haverhill Street........	.022	.050	24.4	5.5	.016	344
Tank 6, for six months............	.014	.074	45.1	11.1	.001	319
Well-water, Mechanic Street..	.016	.076	52.9	42.0	.000	240

waters of wells actually in use at Lawrence and the effluents from filters filtering city sewage.*

The sewage effluents are certainly at least as good for potable use as some of the above waters.

Very marked influence was noted at Altona, upon the germ contents of the filtered water, as a result of scraping the bed of its "dirt-layer." (See table on page 142.)

The table gives the daily performance of the Altona filters during February, 1893, and suggests the wisdom of the policy of wasting the filtrate for a time, immediately after cleaning the filter.

The necessity for this expensive waste, as indicated by the Altona results, does not accord with the experimental experience obtained at the Lawrence experiment station,† nor can it be classed as sound modern practice. If the scraped bed be carefully filled to above the sand-surface with clean water admitted through the underdrains, and filtration be then resumed at a moderate rate, which is gradually increased to the normal flow, there is no reason for obtaining any other than good results.

The necessity for wasting the filtrate after ordinary scraping has not been felt at Albany. A newly cleaned filter is started at a moderate rate of 500,000 to 1,000,000 gallons per acre per day.

When a bed has been refilled with sand, which happens about every two years, the filtrate is wasted for 12 to 48 hours after starting.

It is proper to require a slow and careful filling of the sand-voids with the water admitted through the underdrains, for if such water be passed in hurriedly, disturbance of the sand body

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* Rep. Mass. State Board of Health, 1890 [2], p. 599.

† Ibid., 1893.

by the escaping air will assuredly take place, resulting in the passing of bacteria through the channelways so formed.

NUMBER OF GERMS CONTAINED IN THE WATER OF THE ALTONA WATER-WORKS.

February.	Filter.										R.W.	E.W.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.		
1	....				....			832	....		154	28,520
2	88				212			550	908		142	35,340
3	106				374			R.	76	636	110	40,920
4	123				276			208	96	530	146	31,360
5	176				206			544	84	362	105	33,480
6	418				306			401	82	334	68	39,680
7	234				204			446	94	R.	94	41,660
8	50	22	40	24	28	136	146	368	84	152	130	28,560
9	48	28	R.	32	54	194	152	182	64	122	72	44,140
10	108	50	88	20	28	120	98	110	58	112	126	42,160
11	68	60	76	78	36	140	R.	126	76	204	152	34,100
12	72	58	240	60	38	110	288	80	70	282	82	26,040
13	34	30	560	48	28	82	214	186	86	374	104	24,800
14	40	46	354	24	18	52	164	142	46	364	142	34,080
15	26	28	76	14	18	44	74	48	26	72	49	40,260
16	38	26	84	24	22	52	76	60	R.	120	78	25,420
17	20	36	156	R.	22	48	82	86	324	130	95	26,400
18	26	18	102	54	32	54	112	72	82	126	91	26,440
19	24	20	88	78	28	44	98	82	64	102	70	24,800
20	26	22	70	104	24	36	96	88	34	78	46	19,840
21	20	14	80	68	R.	34	96	44	30	152	50	34,720
22	34	R.	46	62	158	34	68	36	64	*	42	18,250
23	46	246	52	66	138	46	56	54	72	174	68	14,560
24	22	42	32	36	72	22	72	76	34	44	54	11,080
25	18	36	30	28	48	16	48	42	36	38	48	12,360
26	14	20	24	21	34	12	40	36	28	34	32	9,370

R. = cleansing of the filters. R.W. = pure-water reservoir.
E.W. = Elbe water before filtration. * Experiment failed.

Especial care should be taken that no freezing of the sand take place during the time of cleaning. The difficulty of preventing this is, of course, a question involving climate, and for very cold countries the only solution of the problem is the construction of covered filters.

Where open filters are in use in Europe, the attendants depend upon a careful watching of the weather, and very rapid

work during cleaning, to prevent freezing. Should the sand once become frozen, the difficulty is a serious one, for, as was demonstrated at Altona, the water above the sand does not thaw the ice nearly as rapidly as one would expect, and moreover thawing takes place unequally over the surface, whereby a discharge of the whole filtrate occurs through only a fraction of the bed, with most unsatisfactory results.

A recent critic of the filter-bed system refers to the removal, by the bed, of ninety-odd per cent of all bacteria present in the raw London water, and then notes that reduction of the typhoid death-rate has been by no means in so large a proportion. As an explanation of the observed facts, he suggests that the small size of the typhoid bacillus prevents its being arrested by the filter as easily as its larger companions.

In reply it must be said, firstly: Typhoid fever would not entirely disappear from London, or any other city, were the water-supply absolutely sterile, for the sufficient reason that bad water, although a main cause of the disease, is not the only one. Secondly: Filtration is very far from being a simple straining process; were it so, all bacteria would pass the filter with equal facility, for differences between the several sizes of these extremely minute objects would be small indeed as compared with the spaces between the grains of sand. Whatever its size, the bacterium is caught by the zoöglœa jelly surrounding the grains of sand, or is killed by the adverse conditions set up during nitrification, or both.

It is worthy of note that the Massachusetts Board of Health * found that if highly polluted water be filtered and the filtrate be then passed through a second filter, the efficiency of such second filter will be low and remain low for a long time, owing to the lack of the gelatinous coating on the sand grains.

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* Report of 1896, p. 524.

The question of the character of sand most suitable for water-filtration now receives decidedly more attention than it did in the past, for it is recognized that not only must a proper size of grain be secured, but that the degree of uniformity in size must be considered as well. An ideal sand would be one having all of its grains exactly of one size, therefore it is sought to have the "uniformity coefficient" as near unity as possible.

Moreover it is to be remembered that much carbonate of lime present in the sand will harden the water filtered through it.

It is easy to determine the presence of carbonate of lime, by observing whether or not the addition of hydrochloric acid to the sand causes an effervescence, but an accurate knowledge of the amount of the carbonate there calls for a chemical analysis.

A large amount of work has been done at the Lawrence experiment station (notably by Hazen) upon the efficiency of sand,* and the expressions there employed are now widely adopted.

The "*effective size*" of a sand is that diameter of grain than which ten per cent of the sand, by weight, is either equal to or less. It is expressed in millimetres.

If there should be also determined that diameter of grain than which sixty per cent of the sand, by weight, is either equal to or less, and if this value be divided by the "effective size" already found, the quotient will be the "*uniformity coefficient.*"

The mechanical analysis of sands is most easily accomplished by the use of standardized sieves. Those used by the writer are of brass of the following sizes and are "nested":

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* See Reports of Mass. State Board of Health, 1892, p. 541, and 1894, p. 703.

No. of Mesh.	True Size in Millimetres.
100	0.16
80	0.19
60	0.27
40	0.46
20	0.88
16	1.16
10	2.04
8	2.74

It is not possible to purchase sieves of known and accurate mesh, therefore they must always be standardized; and this is best done by the method described in the Massachusetts State Board of Health report for 1892.

For each sieve a definite number of those sand grains are taken which are the last to pass, and which consequently most nearly correspond in diameter with the mesh of the sieve. After counting, these grains are weighed in milligrammes, and their total weight divided by their number will give the weight of one. The specific gravity is easily taken by the bottle method.

Now since the volume of a sphere is equal to $\frac{1}{6}\pi d^3$, and also since $W = V \times$ specific gravity, we have

$$\frac{1}{6}\pi d^3 = \frac{W}{\text{Sp. Gr.}},$$

in which d, the diameter of a sphere equal in bulk to the sand grain, is the only unknown quantity.

Thus the true size of each mesh is secured and recorded.

To analyze a sand, take some definite quantity by weight, say 100 grammes. Place this in the top of the "nest" of sieves and thoroughly shake. Weigh the fine material passing the last sieve, and then add thereto the sand upon this last sieve. The increase in weight will give the catch of the finest

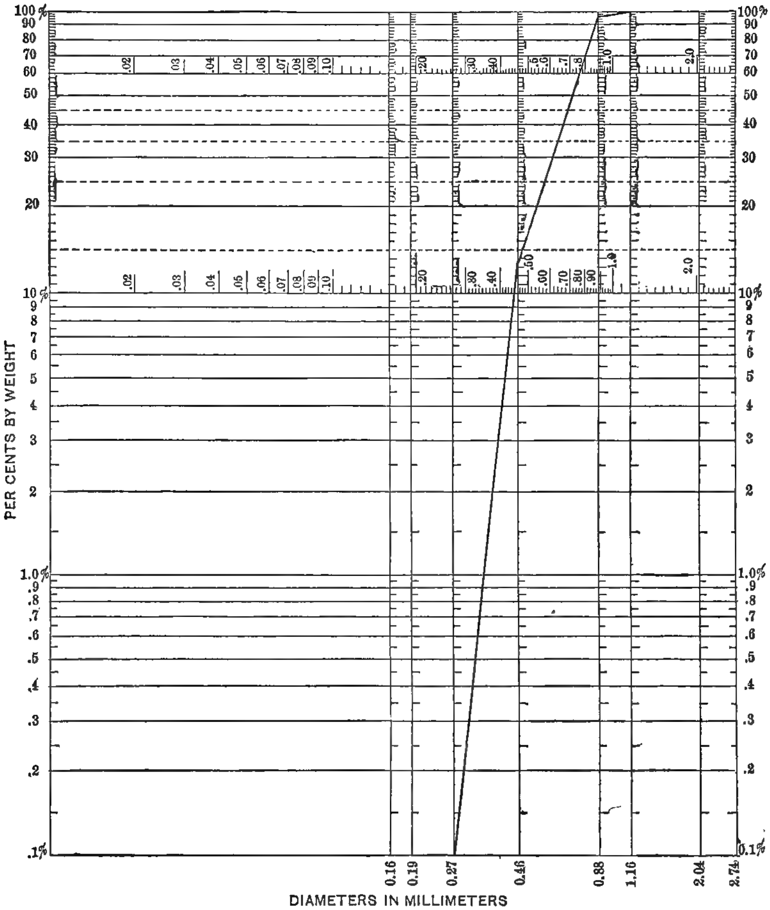


DIAGRAM OF MECHANICAL ANALYSIS OF SAND.

sieve. Without emptying the balance-pan add the catch of the second sieve and note the increase of the weight which will give the weight of the sand arrested by the second sieve, and so on for the entire "nest." Convert these weights into percentages of the original weight taken and plot them as illustrated on page 146. The data for the curve there given are as follows:

Size of Sieve in Millimetres.	Per Cent of Sand passing.
0.16	0.0
0.19	0.0
0.27	0.1
0.46	13.5
0.88	96.0
1.16	99.4
2.04	99.6
2.74	100.0

It will be observed that the curve cuts the ten per cent line at .45 and the sixty per cent line at .76. Hence the "effective size" of the sand under examination is 45 and the "uniformity coefficient" $.76 \div .45 = 1.6$.

Data as determined by Mr. H. W. Clark for sand from some well-known filters are here given:

	Effective Size.	Uniformity Coefficient.
Hamburg	0.31	2.3
Altona	0.37	2.0
Berlin	0.35	1.7
Zurich	0.28	3.2
Liverpool	0.32	2.5

Other data are:

Rensselaer	0.46	1.6
Albany	0.31	2.3
Birmingham	0.57	1.35
Pittsburg	0.30	2.0

A modification of the English filter-bed was some time since proposed to meet the special conditions found at Philadelphia, where the authorities naturally desired to utilize the existing concrete-lined reservoirs. The plan offered was to partition the reservoirs off into sizes proper for filters, and then to build upon the floor a suitable supporting rack to hold the bed of filtering materials; the same to consist of a thin bottom layer of fine gravel, upon which was to rest the usual thick layer of filtering-sand. Filtration was to take place upwards, and washing was to be done downwards, the inlet for raw water and outlet for waste-water being the same. By this arrangement the designer hoped to avoid all complications from ice, the ice-cake being permitted to form freely and float clear of the sand-bed.

During washing a current of air was to have been let into the space underneath the bed, with a view to tumble the grains of sand and break up the sediment, so as to enable it to pass out with the wash-water.

So far as the principle is concerned, there may be little difference between upward and downward filtration, but in pracitce there would be serious objection to the former plan. Much difficulty would be experienced in securing uniformity of work over the whole area of the bed, owing to the impossibility of preventing the dirt-layer falling off in spots, and it is well known that uniform action is of vital importance. It is moreover a dangerous practice to foul a filter in a place beyond reach of inspection and repair, for there is no way of determining whether or not the provided means of cleaning are working satisfactorily. The designer was at pains to state that the scouring action of the air and reversed current of water, during cleaning, could not disturb the proper structure of the bed; but this must be accepted as a doubtful proposition.

MECHANICAL FILTRATION.

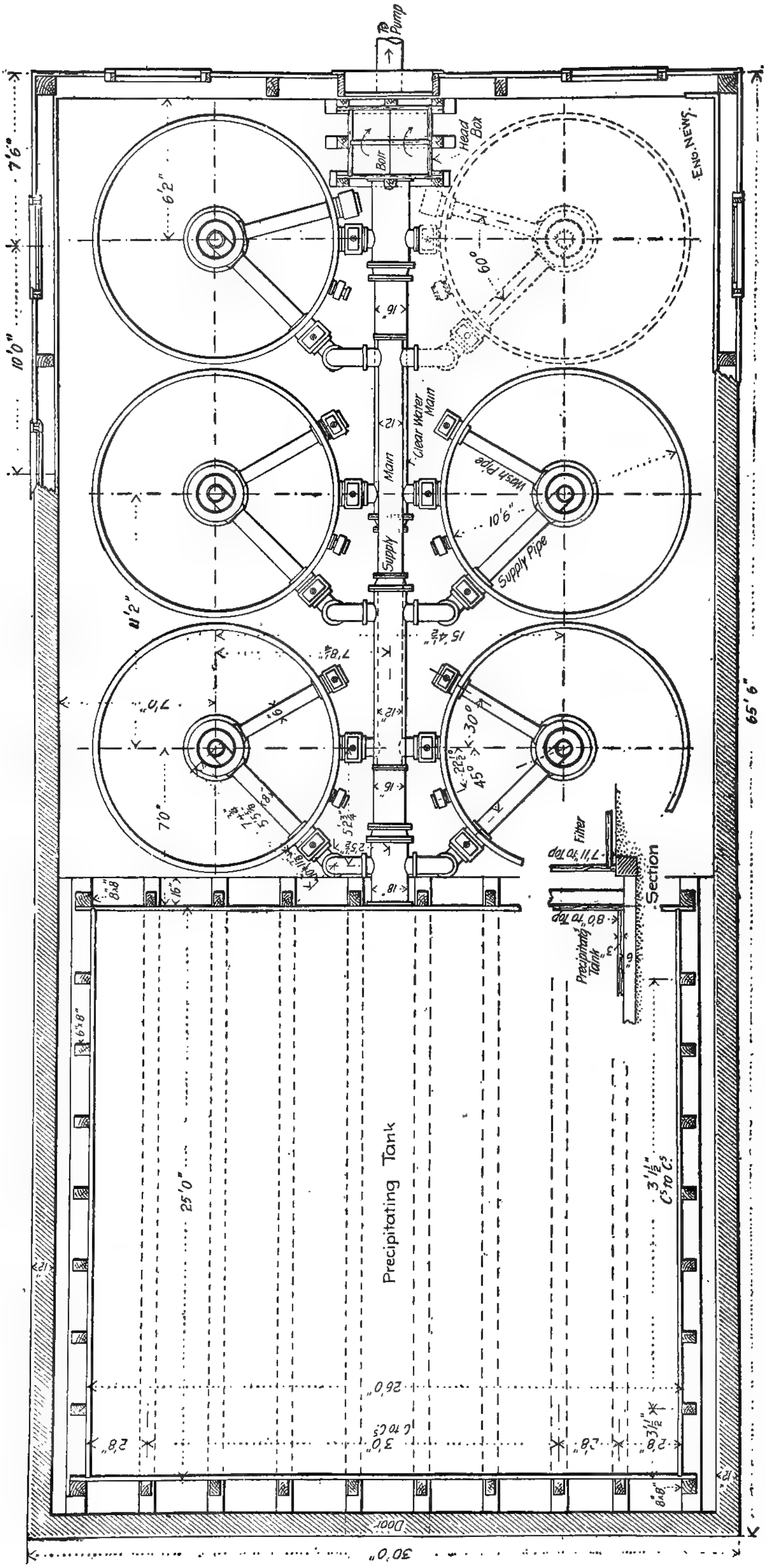
Although the rapid filtration of large volumes o. water through very limited sand-areas is accomplished by appliances patented and controlled by sundry companies of various names, yet the use of such apparatus is so nearly confined to this side of the Atlantic as to warrant the employment of the generic expression "American Filter System."

Roughly outlined, this system consists in adding to the water to be filtered a minute dose of common alum or, better, aluminum sulphate, averaging nearly one grain per gallon, and then admitting the water to the filter, which is a cylinder of wood or iron, three quarters full, of uniformly fine sand. The carbonates present in the water decompose the alum, with the formation of a white flocculent precipitate of aluminum hydrate, quite jelly-like in appearance. For instance, the carbonate of calcium acts as follows:

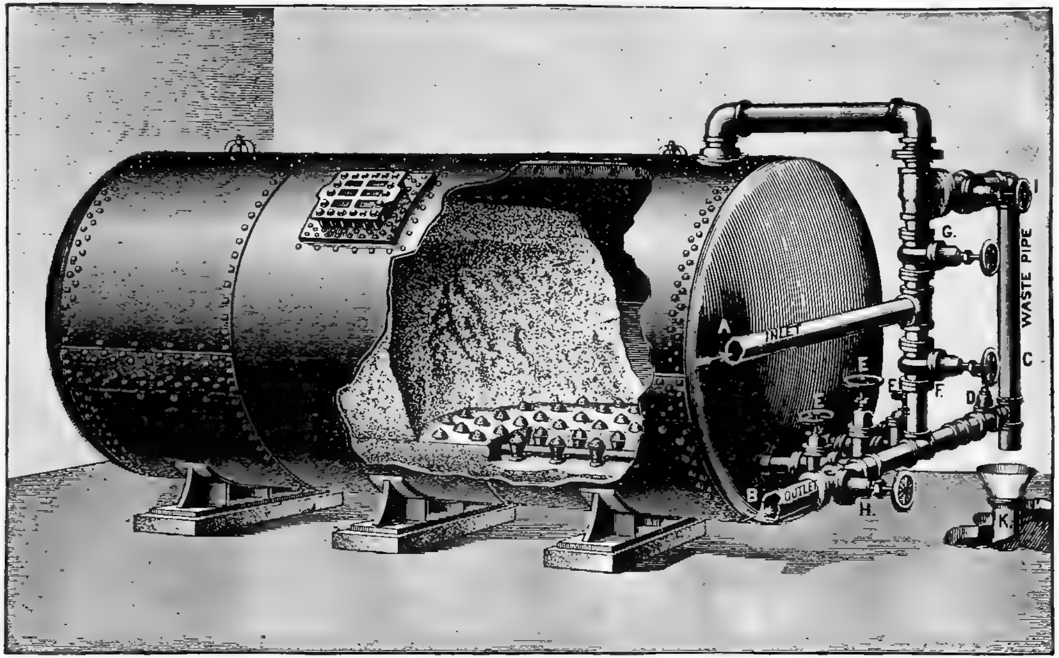
$$Al_2(SO_4)_3 + 3CaCO_3 + 3H_2O = Al_2(OH)_6 + 3CaSO_4 + 3CO_2.$$

The action of this aluminum hydrate is much the same as that of the white of egg in clearing coffee. It entangles all suspended matter, germs as well as inorganic material, and deposits the same on the surface of the sand, whence it is removed and driven into the waste-pipe by a reverse current of filtered water at the time of cleaning the filter. Thus, it will be observed, the mechanical filter produces an artificial inorganic jelly to replace the "bacterial jelly" of the English filter-bed, already alluded to on page 100.

A further action of the precipitated aluminum hydrate is to unite with the soluble coloring matter of the water, whereby the filtrate is rendered colorless. The proper "dose" of alum solution is administered by means of some small automatic measuring apparatus exterior to the filter; the solution flowing



PLAN OF BATTERY OF OPEN FILTERS, WITH SETTLING-TANK.



AUTOMATIC PRESSURE-FILTER.

thereto from the dissolving tank, where the coagulant is prepared in the proportion of twenty parts of water to one part of aluminum sulphate.

For small establishments it is a convenience to make use of a "closed" or "pressure" filter similar to that illustrated on page 151, for the reason that it can be placed directly upon the service-main, thus allowing no interruption in the line of the supply. It is not easy, however, to properly watch such a filter, and it is open to sundry other objections, notably a lack of uniformity in action. For purposes of public use it is inferior to the open or "gravity" type.

On page 154 is given an illustration of such an "open" or "gravity" mechanical filter, a form now in wide use for municipal service. "Units" like the one shown are erected in numbers and sizes suited to the quantity of water to be purified.

The rate at which water is passed through these filters is very great when compared with what is furnished by the English filter-beds already considered. One hundred and twenty-five million gallons per acre per twenty-four hours may be taken as a fair index of what is to be expected of them.

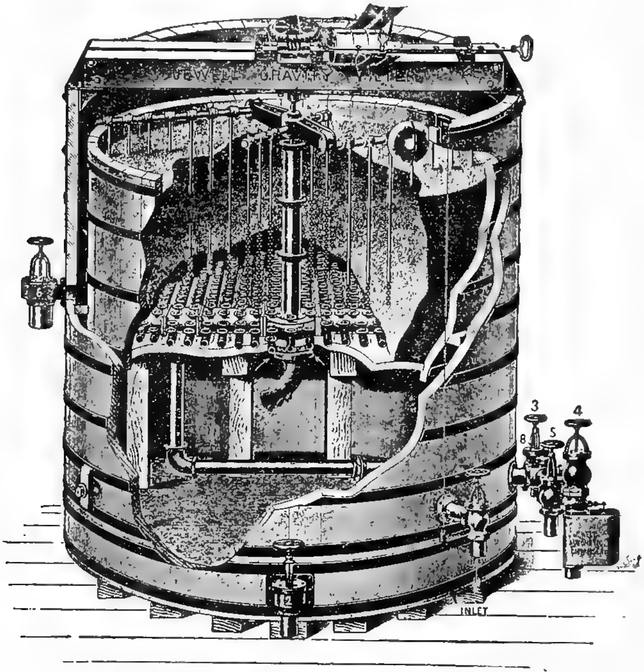
It has been already said that alum is used in their operation. The necessity for the use of this or some other coagulant is imperative and should be impressed upon the mind, for, however well the straining action of the sand-bed may clarify the water, the great rapidity of flow precludes the proper removal of bacteria without they be entangled in the alumina jelly noticed above.

Alum * is by no means the only "coagulant" that could be or that has been used in mechanical filters. Salts of iron were suggested some years ago as a cheap substitute for alum,

* Used henceforth to denote basic aluminum sulphate.

but it is only recently that their use extended much beyond the experimental state.

From the results obtained from the "iron" installation at Loraine, Ohio, it would now appear that the superiority hitherto



"OPEN" OR "GRAVITY" MECHANICAL FILTER, SHOWING SEDIMENTATION-CHAMBER BELOW SAND-BED.

claimed for alum should be seriously questioned, and that in the near future a new coagulant might be the order of the day in mechanical filtration.

Sulphurous acid, formed by burning sulphur and admitting the fumes mixed with steam to a condensing-chamber, is allowed to act upon iron scrap in a revolving drum. The iron sulphite formed is subsequently decomposed with lime, and the resulting iron hydrate acts as a coagulant in a manner entirely similar to the corresponding compound of aluminum.

The advantages claimed for the iron process are: economy in cost of coagulant, no hardening of the water as when alum is used, and freedom from dependence upon the alkalinity of the water for a proper action of the coagulant.

In point of cost the practical results at Quincy, Ill., are reported as follows, per million gallons of water filtered:

175 lbs. of lime........	.40
40 " " sulphur	.80
62 " " iron..	.13
	$1.33

This same water when treated with alum is reported to have cost $4.10 per million gallons for coagulant.

What amount of coagulant should be used is a question best answered by the attendant in charge; for not only will the proper "dose" vary with different plants, but even in the same plant it may differ from day to day, and certainly will change from season to season. One grain per gallon is a fair estimate for a rough one. This amount may be often somewhat lessened with satisfactory result, but also must frequently be materially increased.

It should be remembered that good results are what are looked for, and that if they be not obtained by the dose of coagulant adopted, such dose must be gradually increased until the maximum amount allowable shall have been reached.

The limit of coagulant so used is decided by its cost oftener than by any other consideration.

It is true, as may be seen from the equation already given, that the use of alum increases the permanent hardness of the water because of the formation of calcium sulphate; but the extent of the hardening is commonly insignificant, as an objection, compared with the outlay caused by heavy doses of the coagulant. The influence of turbidity upon the quantity of alum required is an interesting matter worked out by Fuller in

connection with the Louisville experiments. It seems that marked turbidity calls for a dose of coagulant entirely beyond what the soluble salts present in the water demand; and that if the additional dose fall short of what is required by the "absorptive power" of the suspended matter, coagulation fails and the chemical is practically wasted. In view of this, Fuller dwells upon the economic value of sedimentation as a preliminary to filtration of very turbid waters;* the good point is further made that when the water (Ohio River) is muddy, and consequently requires an extra amount of coagulant, with its attending increase of boiler-incrusting salts, the raw water is then so low in such substances as produce hard scale that the total incrusting power of the filtrate is less than that of the raw water when at its clear stage.†

It is worth remembering that theoretically a "dose" of one grain per gallon of aluminum sulphate (containing 17 per cent Al_2O_3) will require about 8 parts per million of "alkalinity" in the water for its complete decomposition.

The actual amount of alum found necessary for purification must naturally vary with the quality of the water operated upon. Thus we find the following quantities in use:

	Source of Water.	Alum used in Grains per Gallon.	Bacteria removed, Per cent.
Warren, O., Average for one year	Mahoning River	2.08	....
Pittsburgh experimental filter*....	Allegheny River	0.70	95
" " " ...	" "	0.72	96
" " " ...	" "	0.78	97
" " " ...	" "	0.98	98
" " " ...	" "	1.22	98½
" " " ..	" "	1 66	99
Rensselaer......................	Hudson River	1.12	....
Louisville experimental filter......	Ohio River	1.75	....
Elmira, N. Y., May, 1901.........	Chemung River	1.38	98.43
East Providence, R. I., 1901.......	....	1	99.24

* See Report of Filtration Commission, p. 56.

* Louisville Report, p. 386.

† *Ibid.*, 248.

The following convenient table is extracted from a publication by a filter company:

QUANTITY OF ALUM (IN POUNDS) REQUIRED PER MILLION GALLONS OF WATER CALCULATING FROM $\frac{1}{10}$ TO 1 GRAIN PER GALLON.

$\frac{1}{10}$ grain per gallon	14.2857
$\frac{2}{10}$ " " "	28.5714
$\frac{3}{10}$ " " "	42.8571
$\frac{4}{10}$ " " "	47.1428
$\frac{5}{10}$ " " "	71.4285
$\frac{6}{10}$ " " "	85.7142
$\frac{7}{10}$ " " "	99.9999
$\frac{8}{10}$ " " "	114.2856
$\frac{9}{10}$ " " "	128.5715
1 " " "	142.8572

Danger to health from the use of alum is a topic fruitful of discussion among the many who are not posted as to its manner of action; but those who are better informed know that free alum never reaches the filtrate in a well-ordered plant.

Alum in the filtrate means a useless waste of material, not to be excused. Reference to the equation already given shows that in order to produce the aluminum hydrate jelly, upon which successful filtration depends, the alum admitted to the water must be entirely decomposed.

The method of testing for free alum is very simple, and the filter attendant, constantly on watch for it in the filtrate, should so manage the "dose" employed as never to allow it to pass beyond the sand-bed. If the judicious use of alum were injurious, the first people to complain would be those using the water in boilers, because of the increased tendency towards formation of scale. Dr. G. T. Swarts reports that after extensive inquiry among cities using such method of purification, and

also among boiler-insurance companies, no objection was discoverable.*

The illustration opposite gives an idea of how a collection of the filtering units is set up.

In filters of that type, stirring of the sand-bed during washing is assisted by the revolving rakes, driven by steam-power, which are best seen in the illustatiorn on page 154. A reverse current of clean water, entering through the bottom valves, loosens up the entire depth of sand and causes the wash-water, with its contained dirt, to overflow the rim of the sand-chamber and fall into the annular space beyond on its way to the sewer.

The amount of filtered water used for purposes of such cleaning is an item for consideration, for it is, of course, lost to the regular volume of supply.

At Elmira the filters are cleaned on the average once in every twelve hours, the time between cleanings varying with the condition of the raw water.

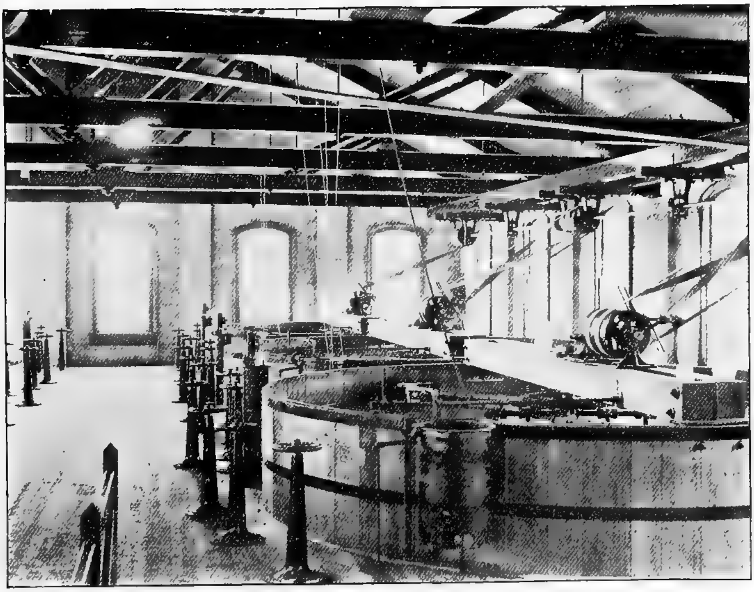
The time required to clean one "unit" is about 3½ minutes on the average; and the water required is about 2.3 per cent of the total quantity purified.

The mechanical plant used in the Washington experiments required 3.7 per cent of the purified water for cleaning the filter.

At Rensselaer the average run is about twenty-four hours, and the filters are cleaned with 3.75 per cent of the filtered water. It takes 8 minutes to wash one "unit."

The mechanical agitators used in filters such as the above are repeated for every "unit." Mr. N. Simin, of Moscow, makes a suggestion which I believe has not yet been tried. He says: "Would it not be possible for the purpose of making filtration cheaper to arrange the filter-plant so that the same agitating device might not be repeated in every filter? I

* *J. N. E. Water-works Asso.*, xiii. 8.



VIEW OF THE INTERIOR OF THE EAST ALBANY, N. Y., FILTER-PLANT.

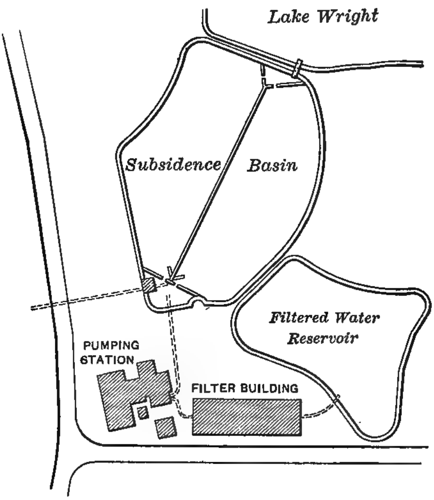
[*To face page* 158.]

mean, to use but one removable agitator, which could be placed in every filter when it is washed, and carried from one filter to another."

One feature of mechanical filtration that has come into prominence of late is the addition of some form of settling-tank. With certain waters it is essential that opportunity be given for sedimentation of a portion of the heavy magma produced by coagulation, otherwise the sand-bed quickly chokes and the labor and expense of cleaning are greatly increased.

This sedimentation, which is subsequent to the introduction of the alum, is variously accomplished.

Thus at Norfolk, Va., a large basin, exterior to the filter-house, intervenes between the point at which the coagulant is added and the filters themselves.



PLAN OF WATER PURIFICATION WORKS, NORFOLK, VA.

As is seen from the sectional cut on page 154 a chamber is provided in some filters of the mechanical type whereby sedimentation advantages are to an extent secured even when the water is far from coming to rest.

The writer having been intimately connected with some extended experiments conducted with such a filtering plant, it

is possible that sundry observations made during the test might be of interest. For the information of those unacquainted with this type of mechanical filter let it be said that each "unit" (of which there were eighteen in the battery at Elmira) consists of a wooden tub about 14 feet high, and open at the top.

The bed of filtering sand, 3 feet 6 inches deep, together with the washing machinery, occupy the upper portion of the tank, leaving below an empty chamber 6 feet high, through which the raw water must pass on its way towards the sand.

To discover just what this lower chamber would do in the way of relieving the filter proper of a portion of its work, was the reason for instituting the test. The dose of alum had been added to the water before the chamber was reached, and the water entered in a tangential direction, near the circumference of the circular bottom, and flowed away through a pipe in the centre of the roof.

Such an arrangement naturally caused the water to take up a movement of rotation, more or less coincident with the surface of a cone whose base was the floor of the chamber and whose apex was the orifice in the centre of the roof.

Upon opening the chamber at the end of the seven days' run, a large quantity of aluminum hydrate was found lying upon the floor in forms like drifted snow and varying in depth from almost nothing near the circumference to 14 inches and more towards the centre of the bottom. Its volume was equivalent to many cubic feet. The best idea of the amount of deposit and of its appearance is given by the accompanying flashlight photograph (on page 161), which also shows uprights, graduated to inches, standing therein.

The photograph scarcely shows one other feature of this aluminum hydrate deposit, which was of considerable interest, namely, the numerous ball-like aggregations occurring throughout the mass. It would seem that the hydrate had in many places been rolled together and built up much after the same

DEPOSIT OF "COAGULATED" MATERIAL IN SETTLING-TANK OF MECHANICAL FILTER.
ELMIRA PLANT.

manner that a boy accomplishes the gradual enlargement of a ball of snow. This formation resulted from the rotary motion given the water by the special device for its introduction already alluded to. Motion such as that is favorable to the formation of large flocks in a liquid in which aluminum hydrate is already formed. Certainly it is a mistake to suppose, as has been so often maintained, that the most rapid "coagulation" and precipitation of the hydrate is necessarily to be secured by permitting the liquid containing it to remain in a state of complete rest. The photographs (on page 165) illustrate that gentle rotary motion, far from being objectionable, is a distinct advantage. The two jars there shown differ from each other but in the fact that the left-hand one had its contents gently rotated, while the contents of the companion was maintained at complete rest. In each the same quantity of hydrate had previously been formed. The photograph indicates how progressively advantageous was the rotary motion for the formation and deposit of large flocks of the hydrate; nor is this to be wondered at when one considers that the movement in question furnished opportunity for more frequent collision, with resulting adhesion, of the growing flocks.

With reference to the bacterial efficiency of these tanks, it was interesting to observe that an average of 42.6 per cent of the germs present in the raw water had been removed by the time the sand was reached.

As a further inquiry a closed pressure filter, operating without a chamber between it and the point of introduction of the alum, was tapped, both above and below the sand surface, whereby it was possible to secure samples of water from various depths in the sand body.

Analytical results showed that the alum was not entirely decomposed, and consequently the chemical equation not fully satisfied until considerable depths in the sand-bed had been reached.

This was to have been expected, in view of the fact that time is an element in all chemical reactions, and a pressure filter, running under the conditions named, allows but small time to elapse after the addition of the alum until the sand is reached.

As a corollary to this proposition, the tanks we have been discussing must also serve as reaction chambers, permitting of more perfect decomposition of the alum, with corresponding completeness of "coagulation."

The efficiency to be expected from mechanical filtration has already been touched upon in the table on page 156, but it is best to supplement what is there given with the following data:

	Average Bacteria in Raw Water. Per c.c.	Average Bacteria in Filtered Water. Per c.c	Bacteria Removed. Per cent.
Norfolk, Va.	356	13	95.99
Loraine, O.	....	....	97 to 99
Elmira, N. Y., May, 1901.	1,848	23	98.43
East Providence, R. I., Dec., 1901.	13,826	44	99 68
York, Pa.	271	3	98.37
Rensselaer, N. Y., April, 1901.	94,500	465	99.48

As already said, the precipitated aluminum hydrate has a marked tendency to unite with soluble coloring matter, which fact makes the alum process of distinct value for removal of the yellow stain so often seen in surface-waters.

When the water is so soft as to be deficient in the necessary quantity of carbonates to decompose the alum added, the bed of ordinary filtering-sand is sometimes replaced by a mixture of such sand and granulated marble, or else the water is hardened by passing it over broken limestone previous to the addition of the alum. A better plan is to add a suitable dose of "soda-ash" to the raw water.

The writer observed that the Norfolk water was increased

PROGRESS OF SUBSIDENCE IN ROTATED AND QUIET WATER.

in hardness from 12.5 to 22.5 parts $CaCO_3$ per million, by passage through a bed of marble and sand four feet in thickness.

Although, as stated, granulated marble is still a portion of some filter-beds where the water to be treated is unusually soft, still the practice of adding carbonate to the water in that manner is not growing in favor, for the reason that the marble is dissolved out of the bed in no long period of time and the required renewal is costly. Such was the experience at Norfolk, Va.

The cost of erecting a mechanical filter-plant is somewhat difficult to give, for the reason that patent rights enter the estimate. It is true that the Hyatt patent for the use of alum has expired, but there are sundry devices dealing with improvements in the filtering apparatus itself which are protected by patents, and which it might be very inconvenient to do without.

Perhaps the fairest general statement that can be made is to place ten thousand dollars per million gallons daily capacity as the basis price for a first-class plant, and to subtract from that some such concessions as the special features of the case may be able to secure.

Filters can be erected for half the above amount, and they do good work for manufacturing purposes; but their bacterial efficiency is low and the water used for washing will be from eight to ten per cent of the delivery instead of about three per cent, as found in the best forms of apparatus.

With reference to the cost of operating a mechanical plant, Mr. E. B. Weston presented the following figures before the New England Water-works Association: *

"I have quite recently estimated $4.73 per million gallons as the cost of operating and maintaining a mechanical filter-plant of 15,000,000 gallons per twenty-four hours available

* Vol. xiv., No. 4.

capacity, while using 0.6 of a grain of sulphate of alumina per gallon, and including interest and sinking-fund, etc., namely:

	Per Mill. Galls.
Sulphate of alumina, 0.6 of a grain per gallon, at $1.25 per 100 lbs., for water and wash-water...	$1.13
Labor and fuel, etc....	1.63
Interest, sinking fund, etc....	1.97
Total.	$4.73

The writer thinks that for a general statement the amount of alum should be raised to at least one grain per gallon, which would about double the price for that item.

Mr. Diven says the cost of filtration at Elmira is $3.50 per 1,000,000 gallons, including interest and depreciation. The plant is some distance from the pumping works, thus requiring an independent filter crew. Mr. Dow R. Gwinn states that the cost of mechanical filtration at Quincy, Ill., is $1.17 for coagulent and $1.63 for other expenses, making $2.80 per 1,000,000 gallons, not including capital charges.

Should the water be highly colored as well as soft, the addition of alum should immediately follow that of the carbonate and a considerable interval should intervene before the filter sand is reached, in order to allow complete reaction and partial sedimentation to take place. The time element is of special importance in the purification of such waters, and is to be secured by the erection of large settling-basins.

The question so frequently asked, as to which system of filtration it is better to generally adopt, American or English, is not capable of a direct answer. Local conditions must first be known.

The writer feels at liberty to commit himself to this extent, however, and say that in his opinion slow sand-filtration is

likely to be the better for very large cities, while for the supply of towns the mechanical system is commonly preferable.

Either method of filtration, to be of value, requires constant attention. Careful watch must of necessity be kept of a mechanical plant, however small, to secure its runinng at all, while very inefficient supervision is the usual fate of the small English sand-bed. Once constructed, it is commonly left to look after itself until cleaning is imperative, and then laborers are put upon the work who have never seen its kind before.

It is very doubtful policy to build an English sand-bed unless the plant be large enough to maintain a skilled force constantly employed. It may be further generally said that, although relatively expensive for small plants, the English system rapidly lessens in cost, per unit of capacity, as the plant increases in size. This decrease is not so rapid for mechanical filters.

Other things being equal, English plants are perhaps better suited for clear waters, and mechanical filters for those of turbid or colored character.

The life of an English filter is practically unlimited, while that of the mechanical type is as yet undetermined.

Finally, it is an easier and cheaper matter to keep the mechanical filter nearer the present requirements as to capacity and to add to it by small extensions as circumstances may demand. So far as bacterial efficiency is concerned, either type will satisfactorily meet the requirements.

Experiments of extended and costly character have been made with a view of securing data whereon to base a decision as to the merits of rival systems of filtration, and it is quite reasonable that the question should be asked, Why is it necessary to multiply such tests? Why cannot Louisville and Pittsburg results be made to do service elsewhere? To a large degree such use is possible, but it must be remembered that waters differ from each other more widely than the bulk of

people appreciate. Thus the mere item of suspended matter is a case in point. Not only does the amount thereof greatly vary, but the character of the material causing the turbidity, and especially its degree of fineness, should command especial attention. Two equally turbid waters may look alike to the eye, but the fine suspended matter of one may be easily arrested by an English sand-bed, while the other may give a filtrate of decided opalescence. Hence the demand for local experiments in important cases.

Nearly akin to the filter-plants referred to above is a group of appliances among which the "Anderson process" is, perhaps, the best known. In this process the water is forced through purifiers consisting of iron cylinders revolving on hollow trunnions which serve for inlet- and outlet-pipes.* On the inner surface of the cylinders are curved ledges running lengthwise, which scoop up iron borings or punchings and shower them down through the water, as it flows through the cylinder. The water issuing from the purifiers or "revolvers" is exposed to the air, whereby the dissolved iron is rendered insoluble, and by filtration through sand this precipitate is subsequently removed, together with what suspended matter it may have entangled.

Excellent results are secured by the Anderson process, but an additional and expensive step is introduced in the item of revolving machinery, before the water is run upon the sand-filters; and it is not proved that this further outlay of capital is necessary, in view of the cheapness of some of the other and simpler methods.

Mr. E. Devonshire, who is an advocate of this system of purification, places the cost of the plant as follows: The revolving machinery alone, adapted to places already possessing filters, would be $5000 per million gallons capacity.

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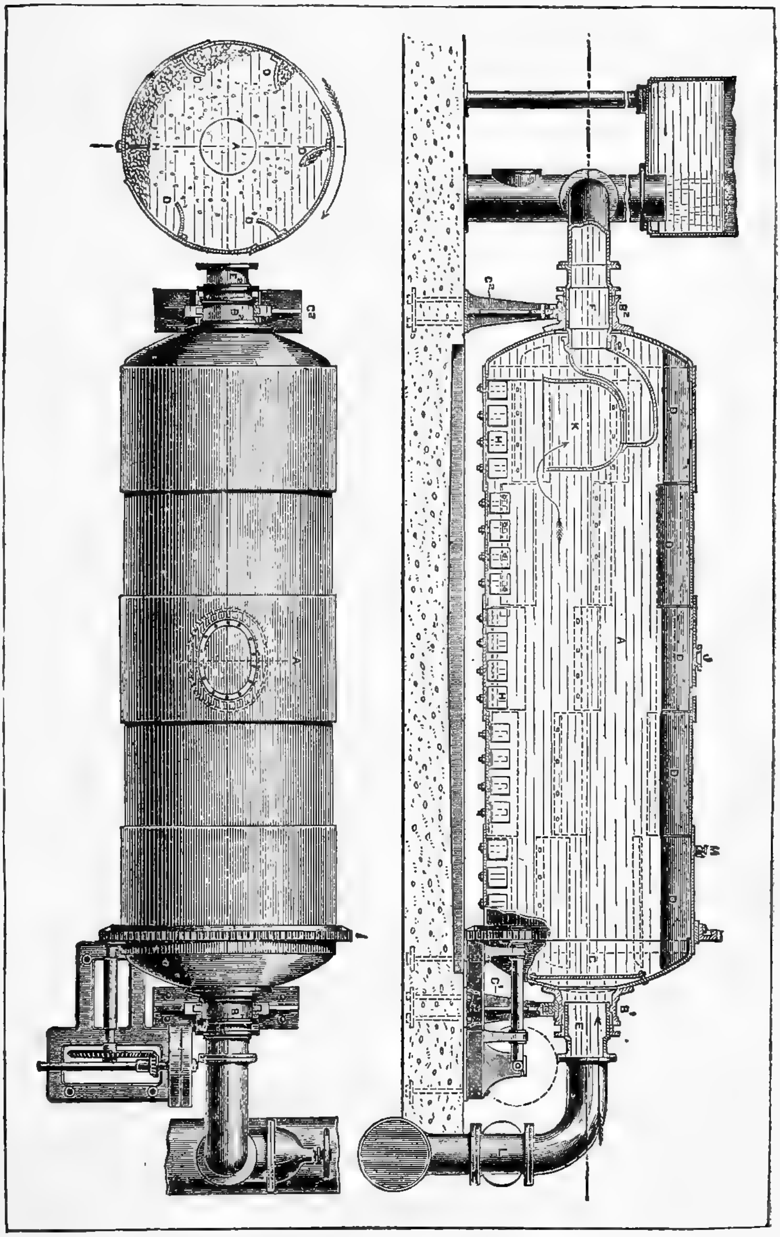
* See p. 171.



"REVOLVER." ANDERSON'S PROCESS.

Where an entire plant is introduced, filters and all, the expense would be $20,000 per million gallons flow. He believes that the working expenses, exclusive of interest charges, would amount to about two dollars per million gallons filtered water.

Through the courtesy of Mr. H. Regnard, of the "Compagnie Générale des Eaux," the writer was given every opportunity to examine the Anderson plant, in operation at Boulogne-sur-Seine, and also the larger one under construction at Choisy-le-Roi. A plan of the Boulogne installation is given herewith. It consists of two "revolvers" * (4 feet 6⅝ inches in diameter and 12 feet 10¼ inches in length) through which the raw Seine water is pumped. The water takes three and a half minutes to pass through the "revolver," after which it is delivered to an "aerator" consisting of inclined troughs with step-like obstructions to break the current. The greater portion of the insoluble ferric hydrate formed in the "aerator" is permitted to deposit in the "decanters" (i.e., long troughs in which the water passes alternately under and over the division-walls) and thence the water passes to the sand filter-beds.

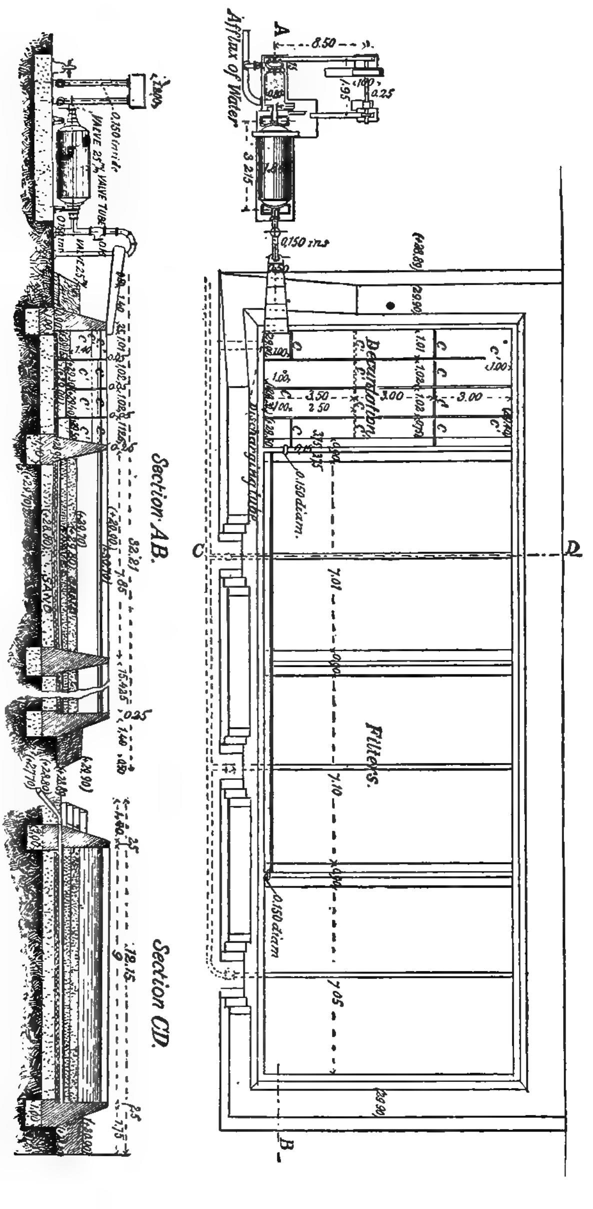
Each drum has a capacity for purifying 2500 cubic metres (660,000 U. S. gallons) of water in twenty-four hours. Four grammes (about 62 grains) of iron are required for the treatment of one cubic metre (264 gallons) of water.

The rate at which the water passes the filters is four vertical metres (about 13 feet) per twenty-four hours.

The "Compagnie Générale des Eaux" has put in a number of Anderson plants, and Mr. Regnard states that the average original cost, including all charges except price of land, is 30 francs ($6) per cubic metre (264 gallons) daily capacity.

The same authority states that the cost of maintenance, including all charges, together with salaries and interest on cost of plant, but excluding interest on cost of land, averages

* Only one is shown in the illustration, p. 173.



ANDERSON PROCESS AT BOULOGNE-SUR-SEINE.

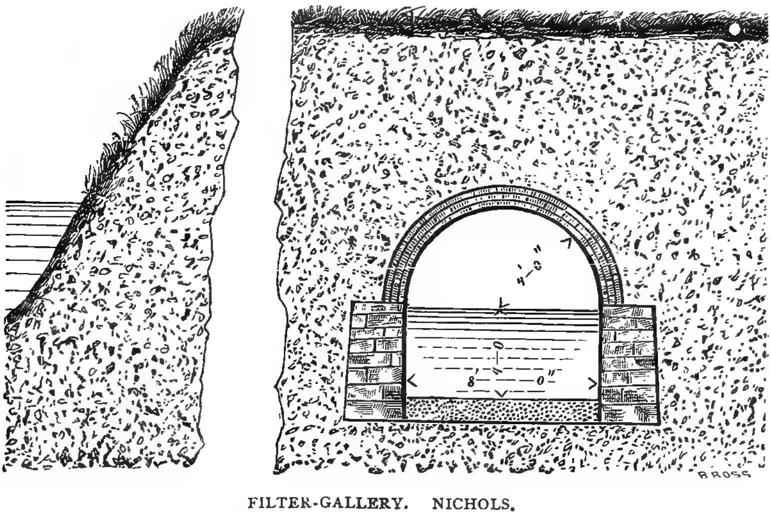
one centime ($\frac{1}{5}$ cent) per cubic metre (264 gallons) of purified water.

The present daily allowance per capita at Boulogne is twenty gallons.

The efficiency of the Boulogne plant has been carefully watched by Miquel, and his average results from thirty-one examinations made during the year are:

Raw water...	333,835	bacteria per c.c.
Purified water...........	1,755	" " "
Percentage of removal....	99.3	

In an attempt to avoid a supposed excessive expenditure of money for the construction of filtering-plants, recourse is at times had to infiltration-galleries built along the banks of a



FILTER-GALLERY. NICHOLS.

stream, or to a filter-crib sunk in the stream itself. The former devices have generally been built in the expectation of securing water from the stream; but in almost every instance the supply obtained has been that which was on its way to the river from

hills, rather than what had already reached the river-bed. In those few cases where river-water is actually obtained, great danger is run of loss in quantity of supply owing to the silting up of the fine passages through which the water flows.

Filter-cribs sunk in a quickly running stream do not easily choke with silt, owing to the clearing effects of the current; moreover, arrangements are sometimes provided by which a reverse current can be made to pass through the filtering-walls of the crib from within outwards.

In either of these two methods for securing a clean water-supply there is this objection, however, that the filtering-apparatus is beyond daily inspection and out of easy control, and may even be beyond repair.

From the sanitary standpoint, the method for purification of water which excels all others in efficiency is distillation.*

The peculiar taste of freshly distilled water is, however, disagreeable to many, and for that reason the process is not likely to become speedily popular, even if the expense be not too great. In a paper before the American Society of Civil Engineers, Mr. Hill advocated the use of distilled water for city supply, and basing his calculation upon one million gallons daily, delivered by small separate distribution-mains, he estimates that the total cost of the water, interest charges included, would be one eighth of a cent per gallon, which would be at the rate of $1250 per million gallons.

Distilled water is used for drinking purposes on practically every vessel in the United States Navy, and Surgeon-General Tryon says: "It may be stated that the medical officers of the navy recognize the great value of distilled water in the improvement in health that has followed its introduction, particularly on certain foreign stations."

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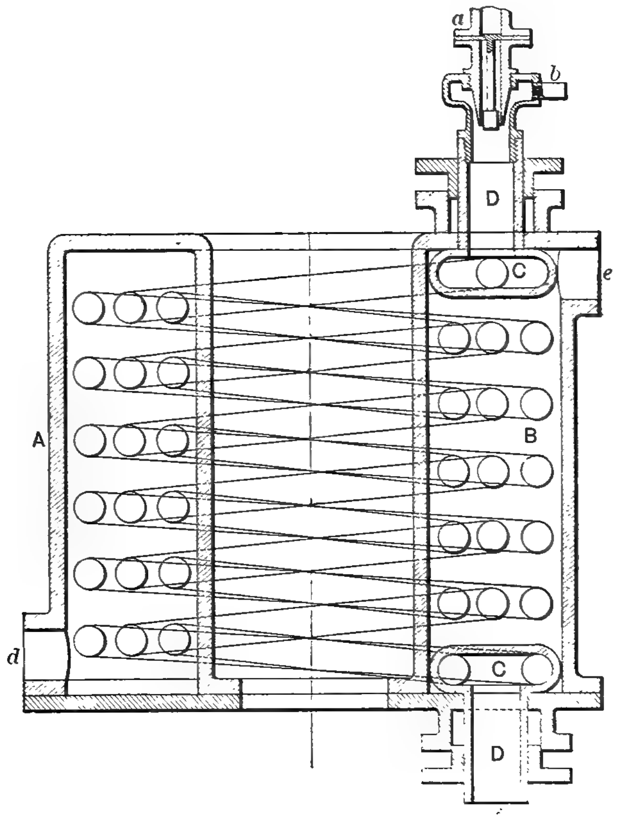
* Further consideration of this question was had on p. 96.

The apparatus used upon these vessels is one devised by Chief Engineer G. W. Baird and called by his name. An especial feature of value is the introduction of the steam into the condenser in such a manner as to drag with it a constant and regulated current of air, thereby causing efficient aeration during the very act of condensation. By this means and the



BAIRD'S CONDENSER.

subsequent passage through a bone-black filter, the water loses much of the disagreeable taste above referred to, and by further standing for some twelve hours the taste entirely disappears.

A few years since a French patent was taken out for

sterilizing water by heating it to 130° C. (266° F.), under pressure, and afterwards filtering it. It is claimed that, inasmuch as the water, during cooling under pressure, reabsorbs the gases driven out by the heat, the objectionable taste of distilled water is avoided.

That complete sterilization takes place at the high temperature attained there can be, of course, no question. Even the spores of the now known pathogenic bacteria are rapidly destroyed by exposure to the temperature of boiling water, although those of certain non-pathogenic varieties will resist that temperature for hours.

During the past year a large multiple-effect distilling-plant has been erected at Fort Jefferson, on the Dry Tortugas, Fla., to furnish water for the naval station and barracks at that place, and to such vessels of the navy as may make port at that point in need of fresh-water supplies. The plant has a guaranteed capacity of 60,000 gallons of distilled water in twenty-four hours, and has been tested to an output 50 per cent in excess of this.*

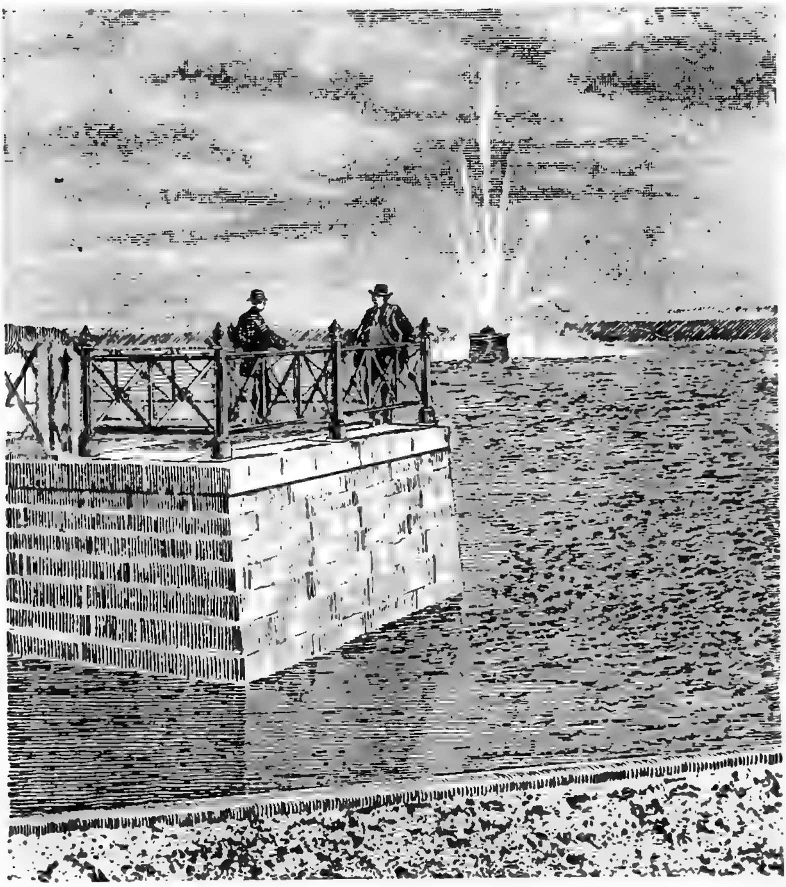
A further illustration of a large distilling-plant may be seen at Gibraltar. The water-supply of that town and fortress is normally stored rain-water, but the authorities are always prepared to furnish distilled sea-water in case of need.

Aeration of water has always held in the public mind a position of prime importance as a means of purification. There is unquestioned benefit arising from the passage of water over falls and rapids, and from its being thrown into the air in fountains, but the benefit is not so great as is commonly believed.

Agitation and aeration tend to prevent the abundant growth of algæ, with their objectionable tastes and smells; and undoubted improvement in quality of water results from the establishing of a fountain in, or otherwise blowing air into, a

* See *Engineering News*, March 29, 1900.

too-quiet reservoir; but the expectations of those who hope to thus easily eliminate pollution of a more serious character will not be realized.



FOUNTAIN IN RESERVOIR AT ROCHESTER, N. Y., WHEN DISCHARGING AT THE RATE OF 3,000,000 GALLONS PER TWENTY-FOUR HOURS. (FROM PHOTOGRAPH.)

P. Frankland * studied the effect of agitation on the common bacteria in ordinary water, and found that "their

* Proc. Royal Soc., lviii. 265.

growth was encouraged by this movement. In the case, however, of sterilized water infected with typhoid bacilli, agitation appeared to hasten the destruction of these microbes." He thought that agitation increased the common water bacteria by furnishing more dissolved oxygen.

Ackermann suggests that agitation is detrimental to typhoid bacilli because it tends to break off the flagella.*

So far as aeration is required to furnish oxygen wherewith the nitrifying germ can do its work, it has already been pointed out that the organism does not suffer any loss of its efficiency even though the oxygen be greatly reduced in quantity below the normal supply. Dr. Drown found, in experimenting on sand-filtration, that there was no advantage in offering the nitrifying bacterium an excess of oxgen; just as complete oxidation was obtained with only three per cent of oxygen present in the atmosphere of the filter as when the full allowance was supplied.

Aeration is of especial value in rendering some kinds of ferruginous well-waters, which are otherwise pure, fit for domestic use. By blowing air into such waters, or even by letting them stand freely exposed to the atmosphere, the iron is oxidized to insoluble ferric oxide, and may be easily removed by filtration.

A German water-supply containing 19.2 parts per million of iron is rendered fit for use by passing through a scrubber of lump coke. Thus both aeration and filtration are accomplished by one piece of apparatus. The deposit of iron on the coke is afterwards removed by washing.

Coke filters ("breeze") are very satisfactory for iron removal, possibly from the action of the iron in the coke, for

* See Frankland's "Bacterial Purification of Water," p. 59.

it has been found that metallic iron in a filter increases the efficiency of the filter for removal of the iron in solution.*

The simple method of iron removal by aeration is indicated when the iron is present in an easily oxidized form. The process may be seen in operation at Asbury Park, N. J., and also at Far Rockaway, N. Y.

At the former plant the water is derived from deep wells (400 to 1100 feet deep) and is raised by an "air-lift." After reaching the surface it is forced through pressure filters of the ordinary mechanical type. Alum is, of course, not used. At Far Rockaway the principle is the same, only an "air-lift" is not required. Sufficient oxidation is secured by allowing the water to spill from the upturned end of the pump-main, after which it is run upon two slow filter-beds which are open and of the English type. In each of the above cases the result is satisfactory.†

Should the iron be present in some form less easy of oxidation, as for instance ferrous sulphate, then its removal becomes somewhat less easy. Again, even if the iron be fully oxidized, it may fail to precipitate, because of there being considerable organic matter present in the water tending to hold it in solution.

Sulphate of iron is successfully removed from the water of Reading, Mass., by the use of lime, followed by aeration and mechanical filtration.‡ Such method of iron removal is expensive and must of necessity increase the hardness of the water. It should therefore be resorted to only after the plan of thorough aeration has been found to fail. Hazen places the permissible limit of iron in a water at 0.5 per million.

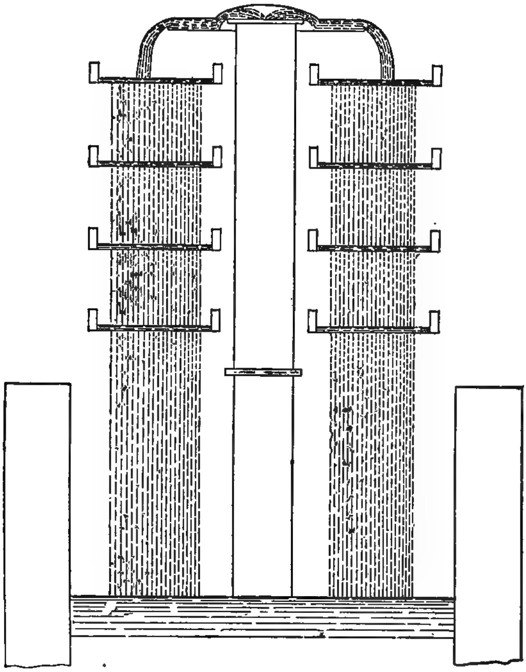
A form of aerator shown herewith is in successful operation at Superior, Wis. The water falls in showers through ¼-inch

* *J. N. E. Water-works Asso.*, xi. 278.

† *Engineering News*, June 4, 1896. and April 12, 1900.

‡ *Ibid.*, June 4, and Nov. 26, 1896.

holes punched in steel plates spaced two feet apart. Very thorough aeration is accomplished with a removal of three



AERATOR FOR IRON REMOVAL, SUPERIOR, WIS.

fourths of the free carbon dioxide.* The separated oxide of iron is subsequently removed by sand-filtration.

In these days of "applied electricity," it would be strange indeed if attempts were not made to harness up the "fluid" for the work of water purification, as an addition to the many other tasks already assigned to it.

In 1888 Dr. A. R. Leeds patented a process for removing the organic impurities in water by subjecting them to the action

* See *Engineering News*, Feb. 21, 1901.

of the nascent gases resulting from the electrolytic decomposition of a portion of the water itself. So far as the writer is aware, this process has not been pushed in general practice.

More recently the attention of the public has been called to the "Woolf" process for water-purification as exemplified in the experiments conducted at Brewster, N. Y., upon a portion of the New York City supply.

The "Woolf" method consists in decomposing a weak solution of common salt (sea-water, for instance) by means of a current from a dynamo, and then adding the electrolyzed liquid to the water to be purified, in the proportion of about 10 grains per gallon of water or 1 part to 5833 by weight.

The product of the electrolysis is fancifully styled "electrozone," but the germicidal power it possesses is due to the well-known sodium hypochlorite formed during electrolysis, and not to the presence of ozone.

The sodium hypochlorite prepared by the Woolf method is not different from that made in the ordinary way, and in germicidal power it is equalled by an equivalent weight of the calcium salt, called "bleaching powder," the efficiency of each being measured by the amount of available chlorine present.

The insoluble salts resulting from the use of "bleaching powder" would, however, be a disadvantage in its use unless opportunity were afforded for settlement, and, moreover, it would render the water harder.

To "disinfect" a water by the use of hypochlorites does not appeal to one as a suitable means for increasing its potability. Mr. Woolf estimates the cost of the properly electrolyzed salt water as ten cents per thousand gallons.

The actual application of ozone in the form of ozonized air to the purification of water has a number of earnest supporters,* but while we wait with interest the further development of such

* Purification of Drinking-water by the Use of Ozone. G. A. Soper, 1899. Also Abstract of Th. Weyl's paper in *Engineering News*, Feb. 8, 1900.

a process we are forced to recognize that it will not remove turbidity unless supplemented by filtration, and that fact places it beyond easy reach in point of expense.

Somewhat recently another electrical purification method has appeared which differs from the older "Webster" process only in the substitution of aluminum for iron in the anode plates. In the "Webster" process, the hydrated oxide of iron resulting from the disintegration of the anode by the passage of the electric current acted as a precipitating agent, and to this action is to be ascribed whatever value the method possesses. In the instance above referred to, where aluminum terminals are substituted for iron, the action is very similar, and purification is accomplished by the precipitating power of the hydrate of aluminum, resulting from the dissolution of the plates. Thus the method becomes really a chemical one nearly akin to the filtration systems using alum. (See page 184.)

During the Louisville experiments G. W. Fuller tested this process and found it efficient, but "out of the question on account of cost." * He moreover noted that "the direct effect of the electric action and the magnetic action was of little or no practical value." †

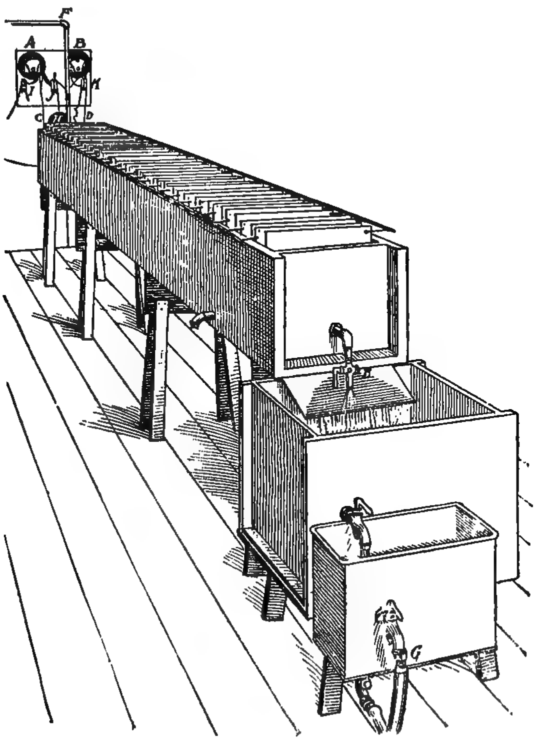
Household filtration on the domestic scale is in very general operation, yet satisfactory results are obtained in an exceedingly small percentage of cases.

The companies manufacturing the mechanical filters previously mentioned all make sizes intended for domestic use, but the skilled labor furnished by a city employé whose sole duty it is to attend to the public plant is very rarely obtainable in the average household; consequently the filter is neglected or mismanaged, or both. In short, filtration, to be effectual, should be municipal. A house-filter that has come widely

* Louisville Report, page 412.

† *Ibid.*, pages 290 and 300.

into use, and upon which very many people pin their faith, is the well-known "Pasteur." It is commonly operated under the pressure of the city mains, but may also be arranged to



ELECTRO-ALUMINUM APPARATUS TO PURIFY 7500 GALLONS IN 24 HOURS.

Raceway 20 feet long and 18 × 16 inches in cross-section, with alternate aluminum and zinc plates four inches apart. The raw water enters through *F*, passes underneath each alternate plate and over the top of every other alternate plate, until it emerges through escape-pipe *E*, where it is sprayed and aerated and goes through *G* into storage-tanks.

A is an ammeter and *B* a voltmeter to measure the electric current utilized. *C* is the positive wire from the dynamo connected with each aluminum plate, and *D* is the negative wire connected with each zinc or iron plate. *H* is a ball and cock which regulates the flow of water. *I*, *J*, and *K* are the switches to make and break the electric circuit. Forty volts and twenty amperes of current are used for this apparatus.

work without additional pressure beyond that of the atmosphere. The cut herewith given shows its simplest form, and, for those unacquainted with its use, it may be said that it con-

sists of a cylinder of fine unglazed porcelain (called "candle" on account of its size and shape) enclosed by one of metal; and that, connection having been established between the latter and the supply-pipe, the water is forced through the pores of the porcelain to the inside of the cylinder (the so-called candle), whence it drops into the reservoir, leaving the suspended matter as a coating upon the "candle's" exterior surface.

Examination of the efficiency of the Pasteur filter has been thoroughly done by a number of investigators, with results that may be summarized as follows: Water can be completely sterilized by filtration through porcelain, but the filtration must not be continued for many days at a time. The length of time during which a sterile filtrate may be obtained will depend upon the temperature of the filter and its contents. Thus, according to Freudenreich, at a temperature of 59° to 64° F. the filtrate was sterile for from 15 to 21 days, at a temperature of 72° F. it was sterile during 9 days, while at a temperature of 95° F. it remained sterile only 5 days.*

Water-pressure is not a factor in causing germs to pass through the porcelain, for their method of penetration is one of development rather than a transporting of initial bacteria; in other words, they "grow" through the filter. Even when the pressure is nil they accomplish the passage in the usual length of time.

From a consideration of these facts the line of management for a "Pasteur" becomes plainly evident. The "candle" and its rubber packing must be removed at least once a week,

* *Centralblatt für Bakteriologie*, xii. 240.

thoroughly washed, and then boiled for half an hour before being reset in position.

Especial care should be taken that the rubber packing make a tight fit, as otherwise the filtrate may pass around rather than through the porcelain. The filter should not be located in too warm a place.

The lateral connecting the filter with the supply-main should be of tin or iron, as the slow action of the filter allows the water to remain for a considerable time in contact with the metal.

An arrangement, suggestive of the Pasteur, is in use on a large scale for filtering the city supply at Worms, Germany. Clean sand mixed with a little soda and silicate of lime is moulded into slabs $3\frac{1}{2}$ feet $\times$ $3\frac{1}{2}$ feet $\times$ 4 inches, and concaved on one side. These are then baked to hard biscuit-ware. Two slabs, placed with their concave sides next each other, form a closed vessel into the cavity of which the water can penetrate through the porous walls, leaving the dirt upon the outside. Series of these pairs connect with the pure-water drains. Material deposited upon the outside of these upright slabs falls to the bottom of the reservoir and is easily removed, while, as additional means of cleaning, a reverse current of live steam may be passed through the system. Although the results obtained by this process are good, they do not appear to be better than those secured by the cheaper and more widely known methods.

As showing the marked advantage to be derived from the introduction of filtered water or of water originally of good quality, the following is extracted from a report of the Minister of War of France, published in the "Journal Official de la République Française" for April 11, 1895, referring to typhoid fever in the French army before and since the introduction of better water:

"To render a more accurate account it will be well to

examine what has been the result in several garrisons where typhoid fever was formerly a prominent and formidable scourge. In the military district of Paris the number of cases amounted to 824 in 1888, and to 1179 in 1889; since the water of the Vanne has been substituted for Seine water the mortality from typhoid was only 299, 276, 293, 258. At the commencement of 1894 the Vanne was accidentally polluted; while typhoid fever visited all the surrounding districts, the garrison itself had 436 typhoid cases, of which 310 were in the months of February, March, and April. During the first two months of this year they had only 8 cases.

"At Beauvais, during three consecutive years, there were 20, 96, and 72 cases of typhoid fever. The use of spring-water since 1891 reduced the number of cases to 2, 9, 8, and 5 for each of the following years.

"The serious epidemic of Auxerre in 1892 affected 129 men; filters were put up, and there was not a single case of typhoid in 1893, and but 1 in 1894.

"At Melun the cases of typhoid have, since the setting up of the filter, decreased from 122 in 1889 to 15, 6, 2, 7, and 7.

"In the garrison of Cherbourg there have been 110 and 119 cases observed in 1888 and 1889; filters were put up in 1890, and the cases of typhoid fever fell successively to 21, 8, 11, 3, and 3.

"We must not forget to speak of the garrison at Dinan, which, having had in three years 835 typhoid cases, has had annually, since filtration of its drinking-water, but 1, 2, 3, and 1.

"Absolutely identical results, due to the same cause, have been noticed from year to year at Montpelier, where the number of cases of typhoid fever fell from 391 to 49, then to 14. At Perpignan, where, after having been 131 and 197, it is now but 18. It was the same at Blois, Vendome, Lure, Auxonne, Vitre, Tulle, Clermont-Ferrand, Chambery, Privas, Avignon,

Toulon, Nice, Tarascon, Beziers, Lunel, etc., etc. In the fifteenth corps there were 1018, now there are only 337; in the twelfth corps, 616 is now reduced to 68. In the garrison of Angoulême, in particular, it fell from 326 to 25; finally, in the eighteenth corps, it reached, in 1888, 292 cases, and is now only 38.

"A progressive and constant decrease justifies the certainty of the effect of the substitution of spring and filtered water for water which the army commonly used in their barracks."

For the whole French army the statistics are:

	Cases.	Deaths.
1886	7771	964
1887	6130	763
1888	4884	801
1889	4274	701
1890	3901	607
1891	3603	561
1892	4820	739
1893	3314	550
1894	3060	530

Many types of household filters are of such character as to preclude the possibility of sterilization, and some of them it is even impossible to clean without the entire renewal of the filtering-material. Such defects are necessarily fatal to proper filtration. The stone filters one sees at times, where the water is caused to drip through fine-grained sand-rock, or similar material, act as mere strainers and are absolutely unreliable. Currier demonstrated that sponge filters, after use for even a single day, furnished a filtrate containing five hundred times as many germs as the unfiltered water. The author has seen household-filters of many types so seriously contaminated that a water could not but be rendered worse by passage through them, and yet such appliances were in full use, and greatly

trusted on account of the apparent clearness of the water drawn from them.*

The unsatisfactory results observed where really good household-filters are in use are unfortunately very apparent, but the fault is more commonly with the attendant than with the filter. The common belief is that a filter, once established, is good for all time, and the author could tell of what he has seen, in otherwise well-organized establishments, that would stagger belief.

Filters once polluted serve as breeding-grounds for bacteria. For instance during the cholera epidemic at Lucknow in 1894 out of 646 members of the East Lancashire Regiment 143 were attacked by cholera and 92 died. Direct proof was had of the infection of the barrack-room filter.†

Much stress is often laid upon the purifying effects of animal charcoal, and the great quantity of occluded oxygen the fresh charcoal contains fully justifies for a time the high praise given it, but such material is nearly impossible to cleanse, and it has been repeatedly shown that a more objectionable appliance could scarcely be found, from a sanitary point of view, than a neglected charcoal filter. For instance, Frankland finds that in the case of such a filter having been in use a month, the filtrate contained 6958 germs per cubic centimetre, as against 1281 per cubic centimetre in the unfiltered water.‡

During the typhoid outbreak which occurred at Providence, R. I., some years ago, a number of private house filters were examined by Dr. Prudden, and three of them were found to contain the typhoid bacillus.§

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* A very full report upon the various types of filters in use, by Woodhead and Wood, may be found in *British Medical Journal*, vol. ii., 1894, pp. 1053, 1118, 1182, 1375, and 1486.

† See "Applied Bacteriology," by Pearmain and Moor, p. 312.

‡ *Chemical News*, lii. 27.

§ *New York Medical Journal*, l. 14.

How very unsafe filters of animal charcoal are, particularly if they be old, may be quickly seen from the following record, made by Percy Frankland, of water passed through a filter composed of six inches of such charcoal, in a state of fine division:

Period.	Organism per Cubic Centimetre.	
	Unfiltered Water.	Filtered Water.
Initial..............	Very numerous	none
After 12 days.......	2800	none
After 1 month.......	1280	7000

The use of the old filter is thus seen to materially damage the water.

For certain special uses, however, the carbon filter is valuable. Thus the writer recommended passing an already filtered river-water through a layer of fine coke in order to remove the last trace of color which was not extracted by the use of alum. An absolutely colorless water was required for the manufacture of a particular grade of paper, and it was secured by such means.

The good old household remedy of boiling a suspicious water is always available, but unfortunately it is but seldom applied. As an illustration of its value it is worth noting that during the cholera outbreak at Lucknow, referred to above, among the members of the East Lancashire Regiment, there was no cholera whatever in company E. This company was the only one which boiled the drinking-water.*

Finally, there is no way of purifying a polluted water, as some people would have us do, by throwing a remedy into the well or cistern.

* Rideal, "Water Purification," p. 151.

In 1873 Crookes proposed the following mixture for addition to the highly impure waters of the Gold Coast before they were used by the troops during the Ashantee War:

Calcium permanganate................	1 part
Aluminum sulphate..................	10 parts
Fine clay.........................	30 "

The mixture does not act quickly enough for use by soldiers on the march. It was found that moving organisms survived for more than a day in an intensely red solution of permanganate.*

* *Chemical News*, lxxi. 43.

CHAPTER IV.

NATURAL PURIFICATION OF WATER.

NATURE disposes in sundry ways of the various elements of impurity added to water, but by far the most efficient of these is the interesting process termed "nitrification." This is a change of state best established by infiltration through soil, a few feet of such passage being capable of doing more to restore a water to its original purity than many miles of flow in an open channel.

Nitrification is accomplished by bacilli whose function is to tear asunder the objectionable nitrogenous organic materials and convert them into harmless inorganic forms, which are at the same time valuable as plant-food.

The conditions under which these little germs can thrive must be met, otherwise the oxidizing action will quickly diminish or even entirely cease. Darkness is favorable and strong light is fatal to the process. A supply of free oxygen must be at hand, but, as has been pointed out by Drown, a small fraction of the amount normally present in the atmosphere will quite suffice for complete nitrification. The presence of a base, preferably calcium carbonate, is necessary to fix the nitric acid formed.

The action of the organism is mainly confined to the upper layers of the soil, i.e., to those portions subject to cultivation, and it rarely occurs below a depth of six feet. This diminution in number occurs in the case of other germs as well, as is shown by Koch. Beumer found in unclean earth forty-four

million bacteria per cubic centimetre at a depth of three metres, and only five million at a depth of six metres. The most favorable temperature for nitrification is 98° F.

One feature of special interest is that the nitrifying organism does not thrive in presence of a great excess of organic matter. It cannot be successfully cultivated in either bouillon or strong sewage. Furthermore, it is noticed that where nitrification is once thoroughly established other germs tend to die out, probably on account of lack of food-supply.

The great importance of this purifying process of nitrification will be better appreciated when we come to consider the question of ground-water, for it is at once apparent that our wells must receive large contributions from drainage material poured into and upon the soil. One thing must be ever borne in mind when depending upon the purifying action of soil, namely, that its power should not be overtaxed by excessive doses of sewage material, and that its filtering action must always be permitted to be intermittent, so that a proper supply of oxygen may be provided. The importance of aerating the filtering soil between the successive applications of sewage has been abundantly shown by the Massachusetts Board of Health, and the advantages of so doing are demonstrated on the large scale at the sewage farm of Asnières, near Paris.*

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* The sewers of Paris, aggregating over 750 miles in length. constitute one of the sights of the city. They may be inspected without charge on the first and third Wednesdays of each month in summer by writing for a permit to the Préfect de la Seine. Descent is commonly made near the Madeleine by a substantial stairway of stone, and the boats awaiting the party at the foot of the steps are fully as large and quite as comfortable as Venetian gondolas.

The great sewer, which is tunnel-like in dimensions, being 16 feet high and 18 feet broad, is, on occasion of a visit, lighted with lamps alternately red and blue, and as these stretch away into the distance the effect is decidedly striking.

Under ordinary circumstances the sewage confines itself to the central channel-way, but upon occasion rises above the sidewalks on either hand. The central channel is about 10 feet wide and 4 feet deep, with a curved bottom and a walk on either side. The boats, with their loads of visitors, are pulled by ropes in the hands of attendants who walk along the sidewalks. On either side of the sewer

Sewage for the purpose of this irrigation at Asnières is conducted throughout the irrigated district in open conduits of earth about 2 feet wide and 3 feet above the surface of the surrounding country. Small side-gates at intervals admit the sewage to the furrows between the rows of growing plants, such gates being opened and the furrows filled whenever, in the judgment of the attendant, the vegetation can appropriate the sewage.

The face of the land is all divided into small sections, in places less than an acre in area, and each such division is flooded independently. What is very important to note is that the filtration of the sewage through the soil is entirely intermittent in character, and that nitrification is given abundant opportunity for full development.

Any surface-clogging of the ground is avoided by suitable use of the spade. So far as the quantity and quality of the crops raised are concerned, they appear to be very near perfection.

Flowing at the base of the gentle slope of the irrigation district is a sparkling stream, several feet wide, consisting of the effluent or underdrainage of the sewage farm. It is full of trout and has the appearance and taste of ordinary drinking-water. The distance of this stream from the nearest irrigation point is about 100 feet. The average analysis for the year 1889 of the sewage admitted to the farm and of the water of the effluent stream mentioned above was as follows:

	Parts per Million.	
	Sewage.	Stream.
Chlorine	78.0	71.0
Organic matter	45.0	1.4
Nitrogen as nitrates	6.8	23.1

may be seen the large mains carrying the city water-supply, and also the telegraph cables.

In this connection it may be incidentally stated that the average composition of city sewage in the United States, as given by Mills, is:

Water	998 parts
Mineral matter	1 part
Organic matter	1 "
	1000 parts

Owing to smaller volume of water-supply per capita, European sewage may be taken as about twice as strong as the average above given.

The conclusions reached by the Massachusetts Board of Health are as follows:

"The purification of sewage by intermittent filtration depends upon oxygen and time; all other conditions are secondary. Temperature has only a minor influence; the organisms necessary for purification are sure to establish themselves in a filter before it has been long in use. Imperfect purification for any considerable period can invariably be traced either to a lack of oxygen in the pores of the filter, or to the sewage passing so quickly through that there is not sufficient time for the oxidation processes to take place. Any treatment which keeps all particles of sewage distributed over the surface of sand-particles, in contact with an excess of air for a sufficient time, is sure to give a well-oxidized effluent, and the power of any material to purify sewage depends almost entirely upon its ability to hold the sewage in contact with air. It must hold both sewage and air in sufficient amounts. Both of these qualities depend upon the physical characteristics of the material. The ability of a sand to purify sewage, and also the treatment required for the best results, bear a very close relation to its mechanical composition."

We have seen that nature makes abundant provision for the removal of pollution from water that is poured upon the soil by oxidizing the objectionable material indirectly through biologic agencies. As to the efficiency of those means, so highly thought of by the people at large, and supplied wherever the water passes over rapids and falls, namely, agitation and aeration, not quite so good an account can be given. Does direct oxidation take place, and, if so, to what extent? With a view of obtaining light upon this question, extended series of investigations have been undertaken with results which have been unsatisfactory. Perhaps the best known are Prof. Leeds' observations of the water of the Niagara River before and after passing Niagara Falls. He found no improvement resulting from the passage over the cataract, and it is but reasonable to conclude that direct oxidation does not seem to be a factor of any considerable importance in the purification of polluted water.

In just this connection, and as a result of his own investigations, Frankland says:

"We are aware that ordinary oxygen does not exercise any rapid oxidizing power on organic matter. We know that to destroy organic matter the most powerful oxidizing agents are required. We must boil it with nitric and chloric acid and the most perfect chemical reagents. To think to get rid of organic matter by exposure to the air for a short time is absurd."

Of course what has been said refers to direct oxidation by atmospheric oxygen and does not cover the possibility of improvement by destruction of objectionable microbes; but, bearing in mind the known powers of resistance of the various bacteria, it is difficult to conceive of any appreciable diminution in their numbers resulting from a short-time exposure of the water in the form of spray.

Neither is it easy to see that the labors of the nitrifying

bacillus can be materially aided by the momentary passage of a fall, when we remember the small percentage of dissolved oxygen required for the fulfilment of its task.

That the said nitrifying bacillus can, under any circumstances, accomplish in a water the quantity of work expected of it in a soil is, of course, not to be hoped for.

It must not be assumed, however, that the old and firmly planted belief of the people is entirely false, and that aeration is without any value whatever. As has been said (page 177), keeping a water well saturated with atmospheric oxygen, either by spraying it in form of a fountain, as at Rochester and elsewhere, or by pumping air into it, either in the reservoir or directly into the force-main, unquestionably renders less likely the growth of some forms of algæ, with their accompanying odors and tastes, and also removes, by direct displacement, any foul gases already in solution.

It is therefore undoubted wisdom to encourage the existing tendency to aerate public waters, but the true action of such aeration must be always kept in mind, to the exclusion of false and exaggerated notions of its value

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Sedimentation is another purifying process upon which wide dependence is placed. Its consideration would properly come under a discussion of lake- and reservoir-waters, but a word should be said here with reference to what may be expected of it in the cases of streams and rivers.

With a view of determining to what extent sedimentation can be depended upon for the purification of streams, the following inquiry was undertaken.

Upon four different occasions (covering various conditions of medium, high water, and flood) samples were analyzed from that section of the Hudson River extending between Troy and Albany. The stations at which samples were taken are situated over one mile apart, beginning at State Street, Troy,

and ending at the Albany intake, five miles below. Two samples were taken at each station during ebb-tide and in mid-channel; one two feet from the surface and the other, as near as could be judged, two feet from the bottom.

The examination of the samples showed sedimentation at all stages of the river, the average being nearly constant throughout the entire distance.

Such sedimentation was, however, found to be decidedly small. An idea of the amount deposited may be obtained from the fact that average differences for total solids between the upper and the lower samples at the end of the second mile was 3.47 per cent of the total solids in the upper sample.

A review of the evidence furnished by the inquiry leads to the belief that sedimentation as a source of river purification in streams such as the Hudson is not nearly so valuable as has been heretofore held. And it would appear, moreover, that a river mainly clears itself by "running out" the suspended silt rather than by depositing the same upon its bed.

So far as the removal of bacteria from river-water by sedimentation is concerned, it must be remembered that, their specific gravities being only slightly greater than unity, they sink but slowly in quiet water, and of necessity still less rapidly in that which is moving. That specific germs do not completely subside during long distances of flow may be inferred from the typhoid statistics already given.

The old notion that water completely purifies itself by freezing has by no means died out, and even after Prudden's able report on the contaminated condition of much of the public ice-supply we find educated people still collecting ice from sources which are grossly polluted.

Organic impurity is commonly more liable than mineral matter to pass into ice, and, inasmuch as the organic impurity

is the more objectionable of the two, the distinction is important.

The inadequacy of cold to purify water from bacterial pollution is more fully referred to upon another page.

It remains to say a word concerning the purifying action of sunlight supplementary to what has been already given on page 69.

Very exhaustive investigations by Prof. H. Marshall Ward show light to have great germicidal action and that "the rays which kill the bacteria are the blue and violet ones. The infra-red, red, orange, yellow, and green are without effect, and the effect weakens as we pass beyond the visible violet."

This explains why these organisms are destroyed so much more rapidly by the light of the summer sun than in winter; why a clear blue sky is so much more effective than a hazy one, and why direct sunlight acts so much more quickly than reflected or diffused daylight." *

Investigations upon this very interesting topic are of recent date, and are, as yet, in an uncompleted form, but enough has been done to show the marked toxic effect of sunlight upon bacterial life and its consequent aid to the effort of the sanitarian. For full and detailed information upon the subject the reader is referred to the recent work of Percy Frankland.† Stated roughly, sunlight is fatal to bacteria sooner or later, the intensity of the action depending upon the kind of germ and the brightness of the light.

Buchner gives a graphic illustration of the action of light, using the typhoid bacillus for the demonstration,‡ and the value of such experiments is very far-reaching, and suggestions of great sanitary importance naturally follow.

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* *Chemical News*, lxx. 243.

† "Micro-organisms in Water."

‡ "Einfluss des Lichtes auf Bakterien." *Centralblatt f. Bakteriologie*, xi. 781.

Of more direct bearing upon our present consideration, however, are the investigations Buchner instituted concerning the action of sunlight upon the typhoid germ at different depths of water. He found that plates of inoculated jelly were sterilized by exposure during 4½ hours at a depth of 5 feet 3 inches in the waters of Starnberger Lake, near Munich; while similar plates exposed during the same period at a depth of 10 feet 2 inches barely exhibited any diminution of virility whatever.

The bearing this point has upon the influence of sunlight upon the self-purification of streams is at once apparent; but it must not be forgotten that a comparatively thin layer of water will cut off an immense deal of the germicidal power of sunlight, and we must consequently restrain our tendency to exaggerate the beneficial action.

In this connection it is worth while studying the antiseptic action (recorded by Procacci) of midday sunlight, in June, upon bacterial life contained in drain-water forty inches deep. The light was passed through the water vertically, side-light being excluded, and the time of exposure was three hours. Comparison tests, kept in darkness, were also made. The results were as follows per cubic centimetre:

	Before Exposure.	Sunshine.	Darkness.
Surface	2100	9	3103
Centre	2103	10	3021
Bottom	2140	2115	3463

The sterilizing action of light upon the upper portion of the water is thus seen to have been very marked.

Self-purification of Streams.

Pettenkofer expresses the opinion * that "ordinary sewage may be, without hesitation, turned into any river or brook whose volume is fifteen times the volume of the sewage, and whose velocity is not less than that of the stream of sewage. Under these circumstances the necessary dilution and self-purification take place after a short flow."

If this were only true, the vexed question of sewage disposal would be very largely disposed of, and enormous sums of money now expended in such disposal would be saved. That it is very far from being safe practice is evidenced by such statistics as have already been quoted showing the serious pollution of large rivers by small streams of sewage inflow. It has been shown (page 34) that twenty-six miles of flow were not enough to protect Albany from the contaminated sewage of Schenectady, even when the rivers in question were so large as the Mohawk and Hudson, and with the high "Cohoes" falls on the route.

Prof. Sedgwick gives an instance of similar carriage by the Merrimac River:

TYPHOID INFECTION CARRIED TWENTY-FIVE MILES BY RIVER.

	Cases Reported.			Deaths.		
	Lowell.	Lawrence.	Newb'port.	Lowell.	Lawrence.	Newb'port.
November, 1892	19	14	0	3	4	0
December, 1892	70	32	4	10	9	1
January, 1893..	38	72	28	10	3	3
February, 1893.	14	23	9	7	12	0
March, 1893....	....	....	....	4	4	1

—*From Mass. Reports*, 1892.

* Fischer, "Das Wasser," 268.

"In the eight months preceding August, 1892, two cases of typhoid were reported in Newburyport, in the subsequent five there were ten; twenty-eight cases in January, 1893, were thus very unusual. These cases appeared in the same month, but earlier than the increase in Lawrence; they were therefore due to infection from Lowell, more than twenty-five miles distant. The people had warning of the danger from Lawrence."

Professor Williams told the writer that in the summer of 1892 a serious epidemic occurred in Detroit, so that the typhoid death-rate in that year was exceeded by that of only four American cities. The cause was finally traced to Port Huron, sixty miles north. The sewers of Port Huron discharged into Black River, a sluggish stream with very little flow. In the spring of 1892 work was begun by the government upon the dredging of Black River to improve it for navigation, and deposits of foul material from the years' accumulation of sewage in the stagnant reaches were removed by dredging, some of these deposits being 8 to 12 feet in depth. This material was taken away in scows and dumped into the swift current of the St. Clair River. Allowing for the time necessary for the water thus polluted to reach Detroit and for the period of incubation of the typhoid germ, the course of the fever in Detroit exactly coincided with the dredging of the polluted material and its deposit in the river, 60 miles above.

In their sixth report (page 138) the Rivers Pollution Commissioners of Great Britain said: "We are led to the inevitable conclusion that the oxidation of the organic matter in sewage proceeds with extreme slowness even when the sewage is mixed with a large volume of unpolluted water, and that it is impossible to say how far such water must flow before the sewage matter becomes thoroughly oxidized."

The inference contained in this old report is not entirely in accord with modern experience, for it will be shown that purifying changes take place with greater rapidity when sewage

is present in water in large rather than in small quantity; but the conclusion of the commissioners, that complete purification is impossible within short distances of flow, is certainly the accepted doctrine of to-day. We no longer look entirely to the chemical examination for our information, and we recognize other elements of harmfulness than merely dead organic waste material, and other means of oxidation than direct atmospheric action; but we believe, as they did, that self-purification of streams is a process not to be implicitly relied on, and that simple dilution enters largely into the safety-factor of those who drink water from a polluted river.

When the question of the self-purification of streams first came to the fore, Pettenkofer's theory held undoubted sway, and short distances of river-flow were considered entirely adequate to the removal of gross pollution. Later on the development of bacteriology threw discredit upon this view, and it was held that a water once seriously polluted could never again be safely turned to domestic use unless artificially purified.

Very recently the investigations connected with the alleged pollution of the Illinois River by the opening of the Chicago drainage-canal have tended to again modify our views, and have caused us to admit that stream-purification is a fact provided the length of flow be sufficiently great. The distance from Chicago to Grafton is some two hundred and eighty miles, and concerning the situation at the latter place Professor Long says:* "It may be safely said that if the whole of the sewage of Chicago were to be excluded from the Illinois River, the condition at Grafton would remain unchanged as far as organic content and bacterial organisms are concerned." In other words, the Illinois River disposes of Chicago's sewage by natural means during the above-mentioned length of run.

However much we are inclined to accept this latest addition to our data concerning the changes induced by river-flow,

* Rep. Illinois State Board of Health, 1901.

one cannot but feel that no upsetting blow has been given to the general proposition that specific infection may cover long distances by water-carriage, and that it would be very rash to prophesy for any particular case just what the limits of such carriage would be.

As dealing with the chemical changes occurring in polluted water during stream-flow, a former investigation conducted by Professor Long is well worthy of attention. He instituted a series of analyses of the dilute sewage contained in the Illinois and Michigan Canal. It is to be noted that this canal received its supply of water (or rather dilute sewage) at Bridgeport, where the pumps delivered to it the filthy water of the Chicago River, contaminated with a great portion of the sewage of Chicago. From Bridgeport the water "flows along the level to Lockport, twenty-nine miles below, requiring about a day for its passage." It received no dilution on the way and was frequently agitated by passing boats. "After passing Lockport the water descends to Joliet through four locks, and falls over a dam seven feet in height to point of collection. There is a fall of 58.2 feet in a distance of four miles, and no dilution takes place on the way." The experiments with this canal-water were both numerous and thorough, and judging from the mean results there is good ground for the statement that very considerable self-purification took place during the flow of thirty-three miles.

The writer has long been of the opinion, however, that what may be true for dilute sewage does not hold good as we approach the limit of potable water.

In other words, so far as purification of a water by the natural processes of oxidation is concerned, the rate of such purification varies directly as the amount of sewage contamination. Given a stream with a certain amount of pollution, the per cent of such pollution which must disappear per mile of flow will continually decrease as the stream flows on.

To return to Dr. Long's figures. The analyses as given by him are as follows, in parts per million:

At Bridgeport:

	Free Ammonia.	Albuminoid Ammonia.	Oxygen Consumed.
June 26	2.6	0.64	12.0
July 3	2.7	0.52	6.8
17	25.0	1.50	22.4
24	5.5	0.37	12.6
31	23.0	1.76	23.2
Aug. 7	26.0	1.50	16.8
14	29.0	1.64	32.0
21	27.2	1.50	28.0
28	29.2	1.90	35.2

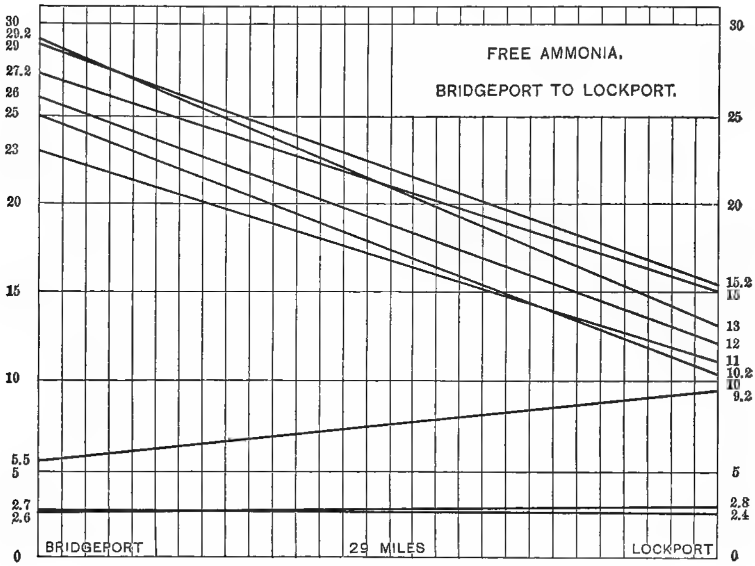
At Lockport:

June 26	2.8	0.56	11.36
July 3	2.4	0.42	7.20
17	10.2	0.72	12.80
24	9.2	0.47	14.80
31	11.0	0.72	10.70
Aug. 7	12.0	0.48	9.60
14	15.2	0.88	9.76
21	15.0	0.84	10.80
28	13.0	0.88	12.40

At Joliet:

June 26	1.7	0.46	7.36
July 3	1.8	0.46	9.76
17	13.0	0.44	14.50
31	9.2	0.44	5.68
Aug. 7	7.5	0.42	5.84
14	9.8	0.46	5.76
21	9.0	0.11	0.52
28	8.0	0.32	6.80

Plotting these in graphic form they assume the shape shown on the accompanying charts, pages 206, 207, 208. The change in lake-level at various dates, together with other disturbing influences, caused comparatively clean water to



SELF-PURIFICATION IN ILLINOIS AND MICHIGAN CANAL.

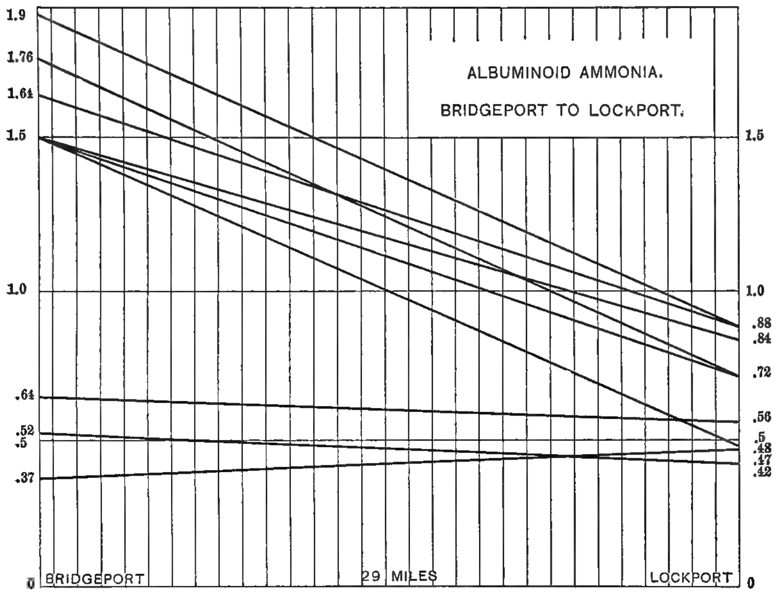
reach the pumps at times, and we therefore are furnished with data governing the purification of several variously contaminated waters while flowing under constant conditions.

It will be noticed that the rate of purification per mile for the more grossly contaminated samples is much greater than that for those comparatively pure. Thus during the flow from Bridgeport to Lockport the sample of July 3d loses 11.2 per cent of its free ammonia and 19.3 per cent of its albuminoid ammonia, while the sample of August 28th loses 55.5 per cent free ammonia and 53.7 per cent albuminoid ammonia while flowing the same distance.

Even the best of these waters of the Illinois and Michigan

Canal was very far from being potable, and we may consequently look for still further reduction in the purification rate as we near the potable limit.

In speaking of the apparent self-purification from organic matter of the river "Wear," Frankland points out that a large



SELF-PURIFICATION IN ILLINOIS AND MICHIGAN CANAL.

amount of water charged with iron from the coal-workings finds its way into the stream, and he calls attention to the potency of iron in various forms for the removal of organic matter from water.*

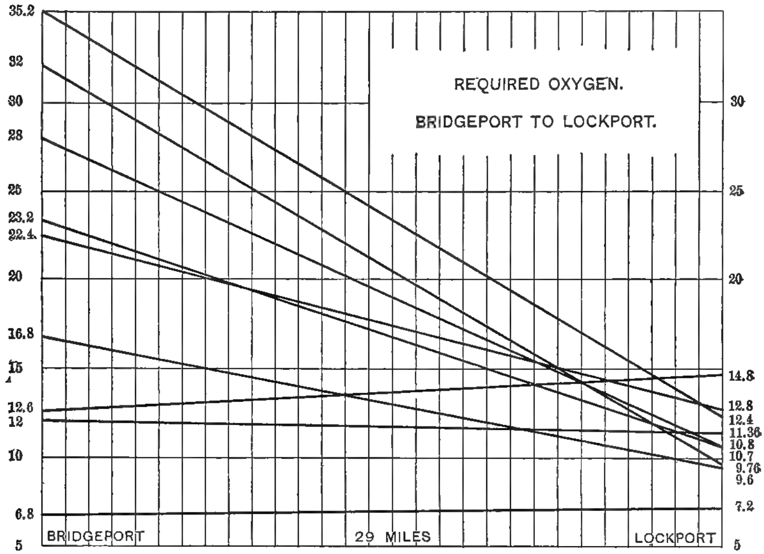
The changes which take place in undiluted sewage are very rapid, as may be seen from the table on page 209.

We have seen that the amount of oxygen dissolved in a water need not be large in order to permit the purification changes inaugurated by nature to go on; but in the event of

* J. Chem. Soc., xxxvii. 529.

the supply of oxygen being entirely cut off, putrefactive reactions are set up with very undesirable results.

An interesting case of this kind is reported by Dr. Leeds as occurring during the winter of 1882–3. The exceedingly bad taste and smell of the Philadelphia water was found by



SELF-PURIFICATION IN ILLINOIS AND MICHIGAN CANAL.

him to have been due to a superabundance of putrescible material, at a time when the dissolved oxygen was unusually small in quantity. The rainfall of the late autumn and early winter had been very slight, thus producing a low state of the river. Polluted water in extraordinary quantity had been admitted by the emptying of sundry dams and canal levels, and the atmosphere was cut off from direct action upon the river by a continuous coating of ice. Under these circumstances the foul-smelling compounds well known to form when organic matter decomposes out of contact with air were produced in large quantity, to the great discomfort of the water-consumers. So considerable in amount were the gaseous products in this

instance that it was possible to ignite them as they escaped from holes in the ice. The flame produced by igniting the gas issuing from a penknife-puncture of the white hollows under the ice is described as being usually six inches high, but once it was "fully a yard high." *

CHANGES OCCURRING IN FRESH SEWAGE UPON STANDING.†

Date	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrites and Nitrates.	Bacteria per c.c.
March 11, 10.30 A. M...	22.5	9.7	3.5	1,190,000
" " 12.30 P. M...	25.0	10.0	3.1	1,085,000
" " 3 P. M...	25.5	10.1	2.9	1,505,000
" " 6 P. M...	28.5	10.1	2.5	1,530,000
" 12, 8 A. M...	49.5	10.8	0.3	20,475,000
" " 12 M...	50.0	11.3	0.2	23,100,000
" " 5 P. M...	50.0	10.2	....	20,000,000
" 13, 10.30 A. M...	51.0	10.0	....	12,810,000
" 14, 10.30 A. M...	50.0	9.5	....	11,235,000
" 15, 10.30 A. M...	50.0	9.3	....	6,825,000
" 16, 10.30 A. M...	50.0	9.3	....	4,485,000
" 18, 10.30 A. M...	51.0	8.3	....	3,420,000
" 19, 10.30 A. M...	52.0	8.4	....	2,341,000

A curious instance of similar character was reported in the Chicago papers of November 2, 1894. Refuse matter had accumulated in so great quantities in the Chicago River that the available oxygen was far too small in quantity for its proper oxidation. Gaseous and inflammable products of sub-aqueous putrefaction resulted, which upon ignition at the surface became almost dangerous to shipping. "The tug A. Mosher was towing the schooner Ford River out of the South Fork, when both boats were surrounded by the fire, which was consuming the gases rising to the surface in huge bubbles."

Judged from the bacteriological standpoint, a considerable monthly and seasonal variation will be observed in the relative

* J. Frank Inst., lxxxvi. 26.

† Rep. Mass. Board of Health, 1894.

purity of running streams. During the low water of summer, although the relative volume of sewage-inflow is large, yet the absence of surface-washings, due to storms or melting snow, usually causes diminution in the number of bacteria present; yet in the case of one wide but shallow river with which the author is familiar, the summer counts exceed those of winter, especially in the vicinity of towns, owing doubtless to the great sewage addition showing itself more clearly during the stage of low water.

The river Seine at Paris shows the following variations in number of bacteria per cubic centimetre, the estimations having been made at Ivry, just above the city, and at two points within the city but above the inflow from the main sewers:

	Ivry.	Austerlitz Bridge.	Chaillot.
Winter	43,500	48,890	91,128
Spring	26,570	33,440	71,845
Summer	13,710	41,635	144,650
Autumn	43,340	53,965	139,700
Mean	31,780	44,482	111,831

Percy Frankland gives the followng counts of bacteria per cubic centimetre in Thames water collected at Hampton:

	1886.	1887.	1888.
January	45,000	30,800	92,000
February	15,800	6,700	40,000
March	11,415	30,900	66,000
April	12,250	52,100	13,000
May	4,800	2,100	1,900
June	8,300	2,200	3,500
July	3,000	2,500	1,070
August	6,100	7,200	3,000
September	8,400	16,700	1,740
October	8,600	6,700	1,130
November	56,000	81,000	11,700
December	63,000	19,000	10,600

At times it chances that some substance of especially marked smell or taste becomes mingled with the general mass of sewage contaminating a water, and a lively sense of pollution immediately takes possession of the consumers. For instance, some years since, a paper-mill dumped refuse containing a little carbolic acid into a tributary of the Passaic River, at a point above the common intake of the cities of Newark and Jersey City. So strong was the odor and taste communicated to the supplies of the two cities that use of the water for drinking purposes was for a time discontinued. The quantity of carbolic acid consumed by each individual using the water was well-nigh infinitesimal and beyond possibility of doing harm, yet serious objection was made to the "pollution" of a stream which was already laden with the sewage of fifty thousand persons residing at the city of Paterson, only eighteen miles above.

Again: The city of Cleveland, O., takes its Lake Erie water from an intake situated beyond the breakwater, and the city sewage passes into the artificial harbor and thence is delivered into the lake at a point well down the east shore. It might be thought that there was little chance of sewage working so far westward against the general trend of current, but it so happens that oily material from the Standard Oil Company's works constitutes a portion of the city sewage, and it has been noticed that a petroleum taste is given the water when the direction of the wind causes an accumulation of sewage in the harbor, which sewage is afterwards permitted to rapidly escape into the lake upon change in the weather. In each of these cases the special material was but a harmless indicator of the presence of the unrecognized but far more dangerous sewage pollution, yet the public strongly objected to the one and calmly accepted the constant presence of the other.

It will be remembered that some years ago, about 1879,

a portion of Boston's water-supply was considered in great danger of contamination with sulphuric acid, owing to the burning of chemical works situated upon one of the tributaries to Mystic Pond, whereby some fifty tons of oil of vitriol were washed into the stream. Mystic Pond is about eight miles below the site of the works, and mill-ponds intervene. Marked acidity was noticed at varying points in the course of the stream and intervening ponds, but no trace of acid remained by the time Mystic Pond itself was reached.

This instance has been often dwelt upon to show how thoroughly nature takes care of even the stable inorganic additions to surface-waters. The introduction of sulphuric acid is sometimes the result of quite natural causes, as when a "mine-water" finds its way into a stream. Such an addition is not necessarily a disadvantage. Thus, in an instance to which the writer's attention was drawn, the acid mine-water with its charge of dissolved iron materially benefited the polluted and highly alkaline stream into which it flowed.

Sundry laws have been passed in various countries, from time to time, dealing with the question of prevention of river-contamination, but none of them, perhaps, is more sweeping than the German act of July 1, 1894. It prohibits the discharge into rivers of—

(*a*) Substances of such a nature that their introduction may give rise to an infectious disease.

(*b*) Substances of such a nature, or in such quantities, that their introduction may involve an injurious pollution of the water or the air, or be a decided annoyance to the public.

A special officer of the province is to determine as to the things and quantities covered by this act.

The recommendations of the English Rivers Pollution Commission (see report of that body) are too long for insertion

here. They are quite detailed in character, and have been criticised as being too severe to be effective.

In America not so much has been accomplished along this line. At a meeting held September 25, 1894, of the American Public Health Association, the following resolutions were adopted:

"WHEREAS, It is the sense of the American Public Health Association that the pollution of potable water in America has reached such a point that the National Government should be asked to take cognizance of the matter, with the view of devising means of prevention and relief; therefore be it

Resolved, That this Association memorialize the Congress of the United States, and ask that they shall authorize the appointment by the President of a competent commission, clothed with power to fully investigate the whole subject of the pollution of rivers and lakes by municipal and manufacturing waste, and provided with sufficient means to enable them to conduct the examination in such a manner as shall be deemed best, the results of said examination to be published from time to time for the public information.

"*Resolved*, That in view of the danger to the public health by the sewage contamination of our fresh-water lakes, rivers, and streams, this Association memorialize the different federal governments, as well as the State and provincial governments, to pass laws prohibiting the contamination of these water-supplies by sewage from cities, towns, and villages, and compel them to provide some means for the treatment and oxidation of this sewage before emptying it into these places."

In Pennsylvania the State Board of Health proposed the enactment of a law from which the following is extracted:

"It shall be unlawful to put the carcass of any dead animal, or the offal from any slaughter-house, butcher's establishment, or packing-house, or any putrid animal substance, or unpurified sewage, or human excrement, or other polluting matter, such

as will render water injurious to health, into the water of, or upon the ice of, any pond, lake, stream, or river in this Commonwealth used as a source of water-supply by any city, borough, or village, within thirty miles of the point where such supply is taken, or to place any of the said polluting substances on the banks of any such pond, lake, stream, or river, or the feeders thereof, within five miles of the point where such supply is taken.

"The State Board of Health shall have the general supervision of all springs, wells, ponds, lakes, streams, or rivers, together with the waters feeding the same, used by any town, village, or city as a source of water-supply, with reference to their purity, and shall examine the same from time to time and inquire what, if any, pollutions exist, and their causes."

Highly desirable as it would be to keep the waters of our great rivers in their natural condition of potable purity, the enormous expense of attaining to even an approximation to that state of things should be considered, and the possibility of causing great injustice to established institutions must be also borne in mind.

Very large centres of population are already in existence which turn their sewage directly into the river upon the banks of which they stand. The up-stream city might well complain should it be forced, at great expense, to establish sewage-disposal plants, when the town below, for much less money, could secure a superior water from some pure inland source.

To the author's way of thinking, a land should be looked upon as watered by its smaller lakes, its springs, and its brooks, and sewered by its great, especially its navigable, rivers. Its water-sources should be protected by law with exceeding care, and no river or stream should be added to its list of drains except after proper consideration by the State Board of Health, followed by legislative permission.

CHAPTER V.

RAIN, ICE, AND SNOW.

SAUSSURE held that a part of the water raised into the atmosphere resembles soap-bubbles.

Clouds he considered to be composed of small vesicles, of which water formed the envelope. And he further believed that every vesicle that rises from the sea must contain a small quantity of the solid matter which was dissolved in the sea-water; the proportion of solid matter taken up in a given space varying according to the relative proportions of these original vesicles that enter into the composition of the clouds.*

The more modern view is stated by Douglas Archibald:†

"Rain is the final stage of condensation of vapor back into water, of which cloud is a half-way stage. The mist which composes a cloud is formed of tiny drops of water about $\frac{1}{3000}$ inch in diameter. It used to be a puzzle to explain how these water-particles were sustained, and it was at one time supposed that cloud-particles were hollow. We know now that this is neither necessary nor true, since very small particles, even of gold, will remain suspended for a long time in air; the finer the particles the longer they take to fall. A slight upward motion of the air is therefore enough to keep them balanced. As condensation proceeds these particles grow larger by fresh coatings of water, and the larger ones fall down against the

* Angus Smith, "Air and Rain," p. 233.

† "The Story of the Atmosphere."

smaller and mingle with them until large drops from $\frac{1}{20}$ to $\frac{1}{10}$ inch thick form, which are no longer capable of being suspended and fall to the earth. Snow forms when the temperature at which this further stage of condensation occurs is below freezing-point.

"Hail is frozen water-drops. It is believed that the rain-drops formed in one part of a storm are carried upward by powerful ascending currents (twenty-five miles an hour is enough to sustain large drops) into higher regions of the atmosphere where they are solidified by the excessive cold, and being carried over with the overflow which takes place near the top, fall down until they are redrawn into the interior of the storm and again whirled up aloft. Receiving alternate meltings and freezings, and growing larger with each circuit they make in the atmospheric churn, they are finally thrown out on either side of the storm-centre. This explains the fact that in a travelling hailstorm there are two bands where hail falls on either side, while under the centre it is often found that only rain has fallen."

The presence of solid matter in rain-water is accounted for by the large quantities of dust of all kinds continually carried into the atmosphere by the winds, and washed therefrom by the falling drops. In the vicinity of large towns various products of incomplete combustion and of industrial waste are added to the atmospheric impurities, and are precipitated along with the more commonly occurring dust;* while in the vicinity of the sea the amount of common salt present increases materially.

The presence of soot in the air causes increase in the rain-water of such impurities as sulphuric acid and ammonia, by what appears to be direct absorption of such material by the

* The English Alkali Act permits the presence of HCl to the limit of 0.2 grains, and of SO_3 to the limit of 4 grains in each cubic foot of air, taken at the foot of the stack of such industrial plants as generate such waste products.

soot. This is shown by Mabery in the following analysis of the air of Cleveland, Ohio: *

WEIGHT IN MILLIGRAMMES PER LITRE OF AIR.

Soot.	Sulphuric Acid.	Ammonia.
87.5	15.2	.070
45.2	6.3	.010
111.3	21.2	.120
41.8	13.9	.003

On September 8, 1894, there occurred the first rain, after the longest period of drought that had been experienced in the State of New York during forty years. Many forest-fires had occurred and the atmosphere had been exceedingly hazy for weeks.

The author collected rain-water, on the above date, in the Catskill Mountains, and the quantity of oily, sooty material it contained was very striking.

A red rain, whose color was produced by dust of probably a cosmic origin, fell upon a number of places in central and southern Europe between March 11 and 13, 1901. Similar abnormal precipitations such as salt rain, rain colored by volcanic ash or by desert sand, and the "bloody snow" produced by growths of *Palmella sanguinea*, have been mentioned by Phipson in his "Researches on the Earth's Atmosphere." † Averages for many years, showing amounts of ammonia and nitric nitrogen carried down by rain at Paris and in different parts of England, may be found in the Report of the Montsouris Observatory for 1897.

The presence of iodine in the rain- and surface-waters of certain districts has been known for years, and it has been claimed, but not satisfactorily proven, that there is a relation

* J. Am. Chem. Soc., xvii. 3.

† See also *Chemical News*, lxxxiii. 159.

between the occurrence of goitre and cretinism and the absence of iodine in the drinking-waters of the places where such diseases are most commonly found.*

The various germs floating in the air, and ready to be carried down by the first shower, do not play a very material *rôle* from the hygienic standpoint, partly because of the improbability of their being pathogenic in character, and partly because of the germicidal power of the direct sunlight to which they have been so thoroughly exposed.

Nevertheless it may be of passing interest to give the official figures issued by the Montsouris Observatory, France:

BACTERIA PER CUBIC METRE OF AIR AT MONTSOURIS.

(Average for ten years.)

January	160
February	145
March	225
April	310
May	305
June	355
July	465
August	455
September	310
October	190
November	195
December	165
Mean	275

A comparison of country and city air shows the following number of bacteria per cubic metre:

Montsouris	275
Centre of Paris	6040

* Angus Smith, "Air and Rain," p. 241

There is a daily maximum of bacteria at 2 P.M. and a minimum at 2 A.M.*

As would have been expected, the Montsouris observations found that the amount of carbon dioxide present in the air of the city was greater during the day, while in the country these relations were reversed.

Rain-water collected twenty-five miles from London is reported as giving the following analytical results, for an average of seventy-three samples:

Organic carbon	.99 per million
Organic nitrogen	.22 " "
Ammonia	.50 " "
Nitrogen as nitrates and nitrites	.07 " "
Chlorine	6.30 " "
Total solids	39.50 " "

Filhol found the following amounts of ammonia in rain-water collected near the city of Toulouse:

* Miquel gives the following comparison, in terms of bacteria per cubic metre, between the air of the Paris sewers and that of the public streets:

	Air of the Sewers.		Air of the Streets.	
	Bacteria.	Moulds.	Bacteria.	Moulds.
Winter	2,385	4,050	3,210	599
Spring	7,165	2,330	11,085	865
Summer	5,110	2,730	12,070	2,340
Autumn	5.400	1,550	7,365	2,320
Mean	5,015	2,665	8,435	1,530

An observation was made upon the air of the St. Antoine Hospital, Paris, showing how large a fraction we retain of the bacteria we respire:

	Bacteria per Cubic Metre of Air.
Before respiration	20,700
After "	40

January	0.60 per million
February	0.82 " "
March	0.83 " "
April	0.44 " "
May	0.55 " "
June	0.77 " "

In the city of Toulouse itself the reading for February was 6.60 per million.

These figures show the marked difference between city and country rain.

Angus Smith and Boussingault place the average amount of ammonia in the rain of temperature climates as 0.5 per million.*

The monthly variation in the chlorine contained in rain-water collected at Troy, N. Y., is given in the following table, the determination having been made in a mixture of the entire rainfall for each month:

January	2.50 per million
February	1.07 " "
March	1.55 " "
April	0.75 " "
May	1.25 " "
June	1.15 " "
July	1.05 " "
August	2.00 " "
September	0.60 " "
October	3.00 " "
November	2.25 " "
December	2.50 " "
Mean	1.64 per million

* For full article on Composition of Tropical Rain, see J. Am. Chem. Soc., xix. 1.

Even casual inspection will often show that rain-water is a long way from being pure, and, high as this "water from the heavens" is rated in the public mind, it is frequently polluted to an extent quite surprising to the collector of the supply.

The author has often noted the confidence with which people will make use of water from a foul cistern, even when the odor of the water is strongly objectionable, because of their entire faith in the purity of the original source.

Thus water from a dirty cistern in West Troy showed the following analysis. In appearance the water was good.

Free ammonia..................	1.050 per million
Albuminoid ammonia..........	.175 " "
Chlorine........................	2.000 " "
Nitrogen as nitrites.............	strong trace
Nitrogen as nitrates............	0.0 per million
Required oxygen...............	2.25 " "
Total residue...................	20.00 " "

The roof upon which rain is caught is a twofold cause of impurity in the collected water; first, because of the material of which the roof is constructed, and, second, because of the foreign substances that may settle thereupon.

In cities the amount of street-dust blown upon the roof and afterwards washed into the cistern is much greater than is commonly supposed. Soot, excrement of birds (often a large item), fallen leaves, and various mossy growths are among the sundry additions to be found in a roof-collected water.

A question of the first importance in considering a rain-water supply is the material out of which the walls of the storage-cistern are to be made. Slate and stoneware naturally suggest themselves as the most suitable materials, but they are not often available, especially if the cistern be a large one. Cement linings, particularly for underground structures, are by

far the most common, and the objection that the lime in them may somewhat increase the hardness of the water is not of much weight, in view of their convenience and low cost.

Tanks of wood serve their purpose well, provided they be kept full; but if there be great fluctuation in the water-line, organic development is liable to occur, and the tank itself falls out of repair. The city of New Orleans possesses many tanks of cypress-wood.

Cisterns of metal are open to a number of objections. Iron rusts and colors the water; lead is dissolved by rain-water very energetically, and is consequently highly objectionable; zinc is attacked, and also galvanized iron. Tin would be a suitable metal, but pure tin would be too expensive, and "tin-plate" would not be sufficiently substantial for such use.

When the controlling circumstances demand a metallic-lined cistern, the metal chosen should be thoroughly coated with a good asphaltum paint.

The commonly employed delivery-pipe which dips into, and remains in permanent contact with, the water of the cistern, should also be coated within and without like the cistern walls.

It is exceedingly important that every cistern should be inspected and cleaned frequently, and upon no point does the public require more instruction than this. The writer could give instances of the grossest kind of pollution of cistern-water, arising from ignorant neglect of what would seem very simple and self-evident precautions.

One form of underground cistern which has been very widely favored in the past is that belonging to the "filtering" type. It is constructed by simply dividing the cistern into two chambers by a vertical brick wall. Water enters one of these divisions and is drawn from the other after percolation through the dividing wall. Such an arrangement cannot be too strongly condemned. The wall is a mere strainer at the best;

it cannot be properly cleaned, and it gives a false sense of security. The very worst case of contaminated water the writer ever saw came from just such a cistern.

The suitable location of an underground cistern is a matter that one might think could be safely left to the good sense of the average householder; but such is very far from being the fact. The writer examined one case in which, on account of a defective lining and a leaky sewer, a portion of the house-drainage was returned to the house along with the cistern-water and used for household purposes. In another instance an unlined cesspool was observed located in a bank ten feet *above* and fifteen feet to the west of the pit furnishing the family's supply of water.

Dr. Smart made a valuable report to the National Board of Health on the rain-water supply of New Orleans, in which he says that he found the wooden cisterns frequently located "in unventilated inclosures, rank with the emanations of unclean privies."

While its softness recommends it for use in the laundry, and while the absence of lime-salts renders it desirable for cooking, rain-water is, on the whole, not to be considered so suitable as a pure ground- or surface-water for general domestic supply.*

Ice, especially in America, is unquestionably to be ranked as an article of food, and the enormous quantity of it consumed may be inferred from the fact that an "ice trust" has been established, under the laws of Maine, with a capital of twelve and a half millions of dollars.

Throughout the colder sections of the country "natural ice" controls the market almost completely, and the dealers

* For a description of the water-supply of Gibraltar see p. 302.

supplying the same "harvest their crop" from the first sheet of water they find conveniently located, without the least inquiry as to its suitable condition; thinking, if they think at all, that the process of freezing eliminates all objectionable features that the water may chance to possess. The author has examined ice from ice-houses deriving their supplies from canals, barnyard ponds, and the like—localities from which no one would ever dream of drawing a supply of water. In the short reach of the Hudson River extending from Troy to Coxsackie, a distance of twenty-seven miles, there are sixty-eight large ice-houses, storing 1,408,000 tons of ice. All of these houses take their ice from the river within the influence of the sewage of the cities of Troy and Albany.

There is a law of Massachusetts, enacted in 1886, to prevent the sale of impure ice:

"Upon complaint in writing of not less than twenty-five consumers of ice which is cut, sold, and held for sale from any pond or stream in this commonwealth, alleging that said ice is impure and injurious to health, the State Board of Health may appoint a time and place for hearing parties to be affected, and give due notice thereof to such parties, and, after such hearing, said board may make such orders concerning the sale of said ice as in its judgment the public health requires."

Ice in very notable quantity occurs in various parts of the world in the so-called "ice-caves" or "glacières." These caves are sometimes of considerable size. Thus, according to Balch, the cave at Dobsina, in the Carpathians, is about 10 metres high, 120 metres long, and some 40 metres broad.

"The stalactites form grand ice-pillars. They are from 8 to 11 metres in height, and from 2 to 3 metres in diameter. In some of the caves, as at Chaux-les-Passavant, the ice stalagmites take nearly the form of cones. There are some seven or eight of them, the tallest of which is at least 6 metres high, with a diameter at the bottom of 5 or 6 metres. Some-

times these cones are hollow, as is the case in a grand one at the Schafloch, some 6 metres or more in height." *

"This great cave was entirely cleared of its ice in 1727 by the Duc de Lévi for the use of the Army of the Saone. In 1743 the ice was formed again. At Szilize, every year, the ice has almost completely disappeared by November, and the cave is free; but in April or May the floor is again covered with ice, and columns and icicles have formed on the roof and sides. At La Genollière the cave is used by the people of the neighboring chalets through the spring and early summer to help in the operation of butter-making."

Cave ice is built up from the freezing of percolating water.

"It is formed entirely by the cold of winter; the heat of summer tends to melt it. Owing to the sheltered position of cave ice the summer heat reaches it with more difficulty than it reaches the snow and ice in the open, and it therefore remains long after the ice in the surrounding country has disappeared."

Reference has already been made (page 198) to the small quantity of purification to be expected from the freezing of water when judged by chemical standards; and Dr. Prudden has also shown how very imperfect the result is when viewed as a bacteriological question.† He gives the following experimental results for the bacillus of typhoid fever:

	Bacteria per Cubic Centimetre yet living in the melted ice.
Before freezing	Innumerable
Frozen 11 days	1,019,403
" 27 "	336,457
" 42 "	89,795
" 69 "	24,276
" 77 "	72,930
" 103 "	7,348

* J. Fk. Inst., March, 1897.

† *Medical Record*, March 26, 1887.

Also:

Before freezing	378,000
Frozen 12 hours	164,780
" 3 days	236,676
" 5 "	21,416
" 8 "	76,032

He found alternate freezing and thawing more fatal to bacterial life than a more prolonged period of continuous freezing.

Professor Dewar finds that bacterial life is very little affected by low temperatures. He says: "I have submitted putrefying blood, milk, seeds, etc., for the space of an hour to a temperature of — 182° C." (i.e., the boiling-point of liquid oxygen), "but found that they afterwards went on putrefying or germinating, as the case happened to be."

The prevalent belief that water purifies itself during the act of freezing is so well fixed in the public mind that the source whence ice is harvested is in consequence usually considered unimportant. This belief is not without support in fact, but like many another partial truth it is a very uncertain foundation upon which to erect the best form of sanitary procedure.

A cake of ice forming, let us say, upon a river thickens by additions to its bottom; in other words, it grows downwards. As the crystals form they tend to shove out and away from themselves all forms of foreign matter which may be in the water, thus purifying the ice layer and correspondingly increasing the pollution of the water by concentration; the amount of such concentration in a river would, of course, be only nominal. Should the ice be formed upon a shallow basin, however, the degree of the concentration might become serious, and if the water should freeze throughout its entire depth all of the impurities present would of necessity be found in the ice and the major part of them would appear in the portion last frozen.

This state of things may be well seen in a cake of artificial

ice made from impure water. All the foreign matter will be observed collected at the centre of the cake, where it was driven and finally entangled by the ingrowing crystals which began their formation at the periphery.

It is not an unknown practice, although a very unworthy one, for icemen to quickly build up their "crop" by flooding the thin ice-field with river-water. As a result the cake grows in both directions; but there is no opportunity for natural purification to take place in the upper or flood portion, which part must of necessity freeze as a whole, thus retaining in the ice everything which may have been present in the water.

With reference to the degree of purification taking place upon the under side of the ice-cake, it is, as already stated, a matter of decided importance, but it is nevertheless much short of what is claimed for it by most of our people.

As the crystals of ice form they are sure to entangle more or less suspended material, particularly that which is specifically light and which therefore tends to hug the under side of the growing cake.

Hence the fact that melted ice often shows more vegetable débris than the water from which it is formed.

Bacteria, whether of harmful form or not, are minute vegetable entities which, though invisible to the eye, are nevertheless suspended in the water and are subject to the same laws of exclusion or entanglement by the ice-crystals as are the particles of larger and visible size.

So far as damaging the appearance of the ice is concerned, bacteria are of no account whatever, but it is wise to repeat here that no reliance must be placed upon the low temperature of the ice to produce destruction of the objectionable organisms.

Typhoid germs are known to live over three months embedded in ice, and Ravenel has lately shown that some forms of bacterial life can withstand the intense cold of liquid air.

Allowing, then, that no sufficient measure of safety can be obtained from the germicidal action of the low temperature of the ice-cake, it is proper to inquire to what extent we may depend upon the growing crystals mechanically excluding germ-life during the process of freezing.

Judging from the results of a recent investigation of the writer's, such exclusion would appear to lie between ninety and ninety-five per cent of all bacteria present in the water,* or, more strictly speaking, the above percentages would represent the bacterial purification from all causes during freezing, of which causes mechanical exclusion is one.

This high percentage of purification deserves this comment, however, namely, the very germs that we are most anxious to eliminate may largely remain among the number retained by the ice, because of their greater powers of resistance, and the large reduction in numbers may be more confined to the harmless classes of organisms. This point is worthy of a passing thought, bearing in mind at the same time the power to resist freezing which Prudden showed was possessed by the typhoid bacillus.

It seems evident, therefore, that if pathogenic bacteria become frozen into the ice-cake there is every possibility that they will reach the consumer in a living condition, and capable of doing mischief, even though a period of months should elapse between the "harvesting of the crop" and the delivery for consumption.

Of course the ideal rule to follow is never to cut ice from a source whence it would be undesirable to drink the water, but like many other ideals this one presents practical difficulties in the way of its attainment.

In view of the very large investment represented by the ice industry it might be unwise and unfair to suddenly impose too severe conditions upon those engaged in the business, but it does seem reasonable to insist that the ice furnished the people

* H. W. Clark finds that the purification accomplished by freezing Merrimac River water amounts to 98 per cent of all bacteria present.

ANALYTICAL RESULTS OF A CHEMICAL AND BACTERIOLOGICAL EXAMINATION OF SAMPLES OF ICE AND THE WATER FROM WHICH IT WAS FROZEN. (PART OF REPORT SUBMITTED TO MANUFACTURERS' ASSOCIATION OF NEW YORK.)

Derivation of Samples. Remarks.	Date, 1901.	Sample.	Color, Platinum Scale.	Sediment, Quickly Falling.	Turbidity, per Clay Standard.	Free Ammonia.	Albuminoid Ammonia.	Chlorine in Chlorides.	Nitrogen in Nitrates.	Nitrogen in Nitrites.	Oxygen required to Oxidize Organic Matter at 212° F.	Alkalinity (as parts of $CaCO_3$).	Total Solids.	Bacteria per Cubic Centimetre.	Bacillus coli Communis.
From Ice-house 18, Map 1, Mohawk Basin. Taken from ice-field during harvesting. Water about nine feet deep.	Feb. 19	Water	.15	Slight	4.	.277	.103	5.5	.332	.005	7.95	52.5	152.	450.	Present
This ice was fifteen inches thick and was clear.		Ice	None	Slight	None	.041	.093	1.5	Trace	None	.8	None	13.	40.	None
From Ice-house 21, Map 1, Mohawk Basin. Taken from ice-field during harvesting. Water about twenty feet deep.	Feb. 21	Water	.15	None	4.	.282	098	6.5	.5	.006	8.07	50.	180.	1440.	Present
The melted ice is, in appearance, inferior to the water. It contains considerable floating vegetable débris.		Ice	Trace	See Remarks	4.	.095	.023	1.	Trace	.001	1.8	None	5.	150.	None
From Ice-house 11, Map 1, Upper Hudson, above Mohawk Junction (middle of river). Water eight feet deep.	March 1	Water	.3	None	15.	.047	.067	1.	.15	.0005	31.3	25.	118.	2100.	Present
The ice was twelve inches thick and much superior in appearance to the water when melted.		Ice	None	Marked	18.	.158	.135	.75	Trace	Trace	5.3	None	103.	42.	None
From Ice-house 16, Map 1, Hudson River just above State dam. Water was thirteen feet deep.	March 5	Water	.25	None	18.	.168	.135	2.	.219	.0015	17.	35.	139	4860.	Present
The ice was ten inches thick, clear, and very fine in appearance.		Ice	None	None	2.	.04	.069	1.	.019	None	1.2	None	20.	70.	None
From Ice-house 23, Map 1, Back channel of Hudson River, below Troy. Water five feet deep.	Feb. 27	Water		None	18.	.327	.448	10.	.875	.02	10.	62.5	247.	91000.	Present
		Ice	None	Considerable	20.	.282	.258	3.5	.112	.002	5.9	None	128.	120.	None
From Midway between Ice-houses 4 and 5, Map 2, below Lower Bridge, Albany. Location exposed to Albany Sewage.	Feb. 22	Water	.3	Slight	6.	.125	147	5.	.25	.002	16.	35.	149	5360.	Present
		Ice	None	Slight	4.	.081	.034	1.25	.125	.001	2.	None	24.	570.	Present
From Erie Canal near Ice-house 15, Map 1, used to fill ice-pond.	Feb. 25	Water	.15	None	6.	.298	.102	6.	.4	.007	6.8	52.5	188.	2000.	Present
Appearance of melted ice inferior to the water.		Ice	None	Considerable	25.	.138	.098	1.75	—	None	2.6	None	75.	60.	None

for use in beverages should show negative results when tested for the presence of the *Bacillus coli communis*.

As concerning the relative merits of transparent and snow ice, Prudden gives the following determinations of bacteria per cubic centimetre contained in two varieties of ice cut from the same cake:

	Bacteria per Cubic Centimetre in the melted ice.
Transparent ice	46
Snow-ice	10,020
Transparent ice	3,192
Snow-ice	15,624
Transparent ice	2,322
Snow-ice	55,062
Transparent ice	218
Snow-ice	9,690
Transparent ice	918
Bubbly-streak ice	26,049

The white ice is richer in bacteria, because it contains large quantities of air, and therefore is capable of more readily supporting the aërobic varieties.

The slower the formation of ice, and the deeper the water on which it forms, the better will be its quality, other things being equal. As the rate of formation decreases as the ice thickens, it follows that the lower portion of a thick layer is purer than the upper. Dr. Drown has strikingly shown the progressive improvement in quality from the top downward, by the analysis of successive fractions of a block of ice which was divided into five layers.

It may not be out of place to interject the following:

Army rules are that two-inch ice will sustain a man or properly spaced infantry; four-inch ice will carry a man on horseback or cavalry or light guns; six-inch ice, heavy field-

guns, such as 80-pounders; eight-inch ice, a battery of artillery with carriages and horses, but not over 1000 pounds per square foot on sledges; and ten-inch ice sustains an army or an innumerable multitude. On 15-inch ice railroad-tracks are often laid for months, and ice two feet thick withstood the impact of a loaded passenger-car after a sixty-foot fall (or perhaps 1500 foot-tons), but broke under that of the locomotive and tender (or perhaps 3000 foot-tons).

Artificial ice is making very rapid strides toward popularity, and if its manufacturers would confine themselves to the use of distilled water as a basis for their product, there is no question but that the confidence of the people would be well placed and permanently retained.

Unfortunately there is a quantity of artificial ice offered for potable use that is made from very ordinary water; and, inasmuch as the usual method of formation causes the water used to freeze as a whole, all the impurities of the water are retained and concentrated in the centre of the cake of ice, that being the last portion to solidify. Unless the water employed be distilled, such artificial ice must, of necessity, be more impure than natural ice frozen from the same water.

The objection advanced above does not, however, apply to a method of preparing ice which has more recently come into practice, whereby the processes of nature are closely imitated, the ice being permitted to form in one direction only.

Snow can be considered only as an indirect source of water-supply, but as such it assumes a position of some importance. The water from melted snow is commonly more impure than rain-water from the same locality, for the reason that its flakes act better than the spherical rain-drops for entangling impurities suspended in the atmosphere, and their low temperature is

conducive to the absorption of ammonia. Analyses of city and country snows from the same general locality show marked differences which are illustrated in the results obtained from samples gathered in the open country and in the city of Troy, N. Y.:

	City Snow. (Troy, N. Y.)	Country Snow. (Menands Station.)
	Parts per million.	Parts per million.
Free ammonia	.460	.15
Albuminoid ammonia	.225	.06
Nitrogen as nitrates	.200	Trace
Nitrogen as nitrites	Trace	Slight trace
Chlorine	1.87	.60
Required oxygen	1.90	1.00

Of course, as is the case with rain, the first portion of the fall must always contain the greatest amount of impurities. The chlorine in city snow (Troy, N. Y.) was thus found to vary during the same storm of two days' duration.

First day	3.05	parts per million
Second day	2.55	" " "

London snow was found by Coppock* to contain:

Total solids	237.3	per million
Mineral matter	89.3	" "
Carbonaceous matter	156.5	" "
Free ammonia	66.3	" "
Albuminoid ammonia	93.0	" "

The first half of the above-referred-to snowfall contained seventy-five per cent of the impurities. The carbonaceous matter was ordinary soot.

Tissandier refers to cosmic dust found in Paris snow. Boussingault found in water from a heavy fog, which had lasted two and a half days, fifty parts of ammonia per million.

After snow is once upon the ground it changes in composi-

* *Chem. News*, lxxi. 92.

tion quite rapidly, particularly in its contained ammonia. This change is, however, greatly influenced by the character of the surface upon which it rests.

Thus the tendency of snow to absorb impurities from the soil is shown by the following comparative analyses of samples taken from a roof and from a meadow:

	Free Ammonia.	Albuminoid Ammonia.	Chlorine.	Nitrogen as Nitrites.	Nitrogen as Nitrates.	Required Oxygen.	Total Residue.	Loss on Ignition.
Fresh snow from roof	.50	.15	.80	trace	trace	.50	22.	7.
Same snow after lying on roof two days..	1.24	.21	.85	trace	trace	2.85	64.	21.
Fresh snow from meadow..........	.27	.11	.75	trace	trace	.40	41.	12.
Same snow after lying in meadow two days.............	.79	.26	.70	trace	trace	2.70	65.	29.

Additional force is thus given to the saying, "Snow is the poor man's fertilizer," and "The fogs and snow remain to fatten the land."

The great influence that melting snow has upon spring-water is shown by the following analyses of a flow from a spring in Rensselaer County, N. Y. The water serves as an illustration, although it is not a "normal" water, as is seen from the high chlorine.

	Oct. 15.	Nov. 10.	Dec. 15.	Jan. 12.	Feb. 5.	March 2.	April 6.	May 8.	June 5.
Free ammonia.........	trace	trace	.015	.010	.025	.027	.025	.01	.01
Albuminoid ammonia..	.036	.03	.055	.035	.090	.078	.060	.04	.07
Nitrogen in nitrites....	.000	.000	.000	.000	trace	.000	.000	.000	.000
Nitrogen in nitrates....	.116	.075	.15	.15	trace	.30	.15	trace	.05
Chlorine.............	20.5	17.3	19.	19.	21.	20.	21.5	18.	17.
"Required oxygen"...	.000	.1	.4	1.15	1.5	1.0	.3	.1	.5
Total solids..........	570.	570.	558.	534.	579.	543.	554.	553.	552.
Loss on ignition.......	.....	79.	62.	44.	114.	73.	63.	48.	52.
Temperature F°.......	53.6	49	46.4	44.6	41	43.7	42	50	51.8
Bacteria per c.c........	158.	750.	1620.	2519.	166.	8520.	476.	.....	.....

The wholesomeness of snow-water has been gravely questioned by a number of investigators; notably by Dr. Chas. Smart, of the U. S. Army. He holds that the malarious poison contained in such water is to be counted as the cause of mountain-fever.*

A detailed account of an outbreak of "aqua-malarial," or mountain-fever, among U. S. troops stationed in Utah, is given in Buck's "Hygiene," page 132. The disease is ascribed to the use of snow-water, and it is stated to be a widely known fact among the native trappers that free use of water derived from the melting snow in the spring will produce the disorder. It is difficult, however, to entirely eliminate the influence of cold nights and hot days with free use of ice-cold water from the presumed effect due alone to the snow.

Dr. Frederick A. Cook,† the ethnologist of the Peary North Greenland Expedition, tells us that the northern Eskimo lives wholly on meat, about two thirds of which he eats raw or frozen. The men are about five feet one and a half inches high, and weigh about one hundred and thirty-five pounds. They drink melted ice or snow for their water for ten months out of the twelve, and really have only two months out of every year of a virile existence. They never wash, and beyond a little rheumatism or a mild attack of *la grippe* they enjoy good health. They are fat and rounded like little seals.

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* *Am. J. Med. Sci.*, Jan. 1878.

† *New York Journal of Gynecology and Obstetrics.*

CHAPTER VI.

RIVER- AND STREAM-WATER.

A VERY large number of cities derive their water-supplies from rivers—in Europe after careful filtration, but in America usually without such purification.

One of the important things for the consumer of such a water to bear in mind is that sudden and great changes in the character of the water are to be expected.

For instance, the water of the Hudson River, sampled at a point above direct sewage-inflow (although below several large towns), shows the following variations:

	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrites.	Nitrogen as Nitrates.	Chlorine.	"Required Oxygen."	Total Residue.	Loss on Ignition.	Suspended Matter. (Silt.)	Temperature, F°.
1894.										
Nov. 3.	.030	.087	000	trace	3.5	3.76	73.	35.	88.4	......
Dec. 15	.045	.150	trace	.15	4.5	13.00	107.	42.	68.8	36.
1895.										
Jan. 12.	.025	.080	000	.10	3.5	7.65	43.	39.	000	......
Feb. 5..	.055	.100	000	.15	......	8.85	88.	45.	000	34.6
March 4	.085	.150	trace	.10	......	10.00	93.	51.	000	33.
April 5.	.042	.235	trace	.30	2.4	5.90	388.	88.	11.	46.4
April 10	.058	.660	trace	trace	......	15.50	583.	74.	495.	41.
May 8..	.030	.205	trace	.10	2.5	7.30	67.	31.	000	68.
June 5..	.045	.120	000	trace	3.5	8.70	78.	50.	000	71.
Sept. 20	.280	.320	.0015	.30	5.0	2.65	......	......	......	......
Oct. 30.	.055	.155	trace	......	3.5	14.85	101.	57.	000	44.

A river-water which is clear to-day may be muddy and less fit for use to-morrow.

Another change, slow in operation but serious in result, is that induced by the establishment of sewerage systems in up-stream cities, through the growth of the population, which naturally sewers into the river. Touching this latter point, the author reported as follows upon a river-water proposed for city supply:

"Its analysis to-day is far from being a measure of its sanitary condition a few years from now. The cities and towns above are beginning to put in sewers, and the day is not far distant when the river will be marked by the inferiority of its water."

Fischer gives the following seasonal variations for the water of the Danube:

	Suspended Material.	Dissolved Material.
Spring	121.9	177.1
Summer	165.4	146.0
Autumn	76.5	178.6
Winter	14.8	199.0

He found the Rhine water to vary between these limits for high and low water in 1886:

Suspended material	249 to 12
Dissolved material	246 to 203

Klinger's results for the river Neckar are:

	Suspended Material.	Dissolved Material.
March, 1888	373	272
April, "	0	382
June, "	0	400
August, "	0	397
September, "	65	440

It is to be noted that the bulk of variation lies in the item of suspended material, and that what is in solution is much more constant in amount.*

* For sundry American data by E. G. Smith see *J. Am. Water-works Asso.* 1896, p. 88.

Below is a statement of the number of days in each month, for 1891, that the Hudson River at Troy was "dirty" with suspended silt:

January	17 days
February	24 "
March	29 "
April	30 "
May	0 "
June	0 "
July	5 "
August	3 "
September	0 "
October	0 "
November	17 "
December	31 "
	156 days

The influence of autumn rains and the melting snows of winter is here well illustrated. The subjoined table is extracted from the *Engineering News* of August 10, 1893, and shows what a large item the suspended matter of a river may amount to when considered in the aggregate.

DISCHARGE AND SEDIMENT OF LARGE RIVERS.

River.	Drainage Area, Square Miles.	Mean Annual Discharge, second-feet.	Sediment. Total Annual, Tons.	Ratio by Weight.	Height Column, one square mile base, feet.	Depth over Drainage Area, inches.
Potomac	11,043	20,160	5,557,250	1 : 3,575	4.0	.00433
Mississippi	1,214,000	610,000	406,250,000	1 : 1,500	291.4	.00288
Rio Grande	30,000	1,700	3,830,000	1 : 291	2.8	.00110
Uruguay	150,000	150,000	14,782,500	1 : 10,000	10.6	.00085
Rhone	34,800	65,850	36,000,000	1 : 1,775	31.1	.01071
Po	27,100	62,200	67,000,000	1 : 900	59.0	.01139
Danube	320,300	315,200	108,000,000	1 : 2,880	93.2	.00354
Nile	1,100,000	113,000	54,000,000	1 : 2,050	38.8	.00042
Irrawaddy	125,000	475,000	291,430,000	1 : 1,610	209.0	.02005

"The first column gives the name of the river; second, its drainage-area in square miles; third, the average annual discharge of the river in cubic feet per second. The fourth column gives the total amount of sediment, in tons, annually transported by the river; fifth, the ratio of the weight of this sediment to the weight of the water annually discharged; the sixth, the height of a column in feet, having a base of one square mile, that the sediment would cover; and the seventh, the depth in inches that the drainage-area would be covered if this total amount of sediment should be spread over it. The discharge- and drainage-areas of the Rhone, Po, Danube, and Uruguay are taken from a paper by John Murray in the *Scottish Geographical Magazine* for February, 1887. The drainage-area of the Nile was measured by planimeter from the best maps obtainable."

River-waters contaminated with special and unusual materials are at times met with. Thus the well-known Rio-Vinagre of South America contains 1100 parts of free sulphuric acid and 1200 parts of free hydrochloric acid per million of water. The quantity of free sulphuric acid carried by it to the sea is over fifty tons daily.

Some streams of Norway and Sweden furnish water so impregnated with infusion of woody material as to be destructive of fish. Frankforter found "tannates" and "gallates" in the water of the upper Mississippi, due to the enormous number of logs floated down the stream from the great forests of the North.

Judged also from the bacteriological side, flowing water will always show large variation in composition at different times, principally due to introduction of impurities carried down by storms from surface sources. Variation will also be noted at different points of the length, breadth, and depth of the same stream, as common judgment would expect, arising from

irregularities in mixing of tributary waters, and from changes in the rate of sedimentation.

Tidal action has also much influence upon the variation in character of certain river-waters. The author has in mind several cities, situated upon large streams, which pump fairly good water during ebb-tide, but whose sewage is carried up-stream by the reversed current of flood-tide, to and beyond the intakes, with exceedingly bad results.

All such points are to be considered when selecting the position for a city's intake.

As supplementary to what has already been said regarding the self-purification of streams, a word may be added to the effect that when the end desired is the prevention of the sewage-inflow to a river becoming a nuisance, rather than the preservation of the potable character of the water, then unquestionably falls and rapids become of material value, for they are the means of increasing the supply of dissolved oxygen held by the water, and upon the quantity of such oxygen present the capacity of the stream to satisfactorily dispose of the sewage-inflow largely depends.

RAINFALL, EVAPORATION, AND FLOW OF STREAMS.

Rainfall is greatest within the tropics and near the sea, and it lessens near the poles. The average annual precipitation for the north temperate zone is usually estimated as 35 inches.

One inch of rain falling upon an area of one square mile corresponds to 2,323,200 cubic feet of water, or about 17,500,000 U. S. gallons.

"On the southerly slope of the Himalayas, northerly of the Bay of Bengal, at an elevation of 4500 feet, the rainfall for 1851 was 610 inches." (Fanning.) Of this amount 147 inches fell during the month of June.

Crooks gives the following averages for annual rainfalls in inches:

Madrid	10
Vienna	18
St. Petersburg	18.4
Stockholm	20.4
Berlin	22.8
Paris	22.8
Hanover	23.2
London	25.2
Rome	31.2
Genoa	47.2
Bombay	79.2
Havana	92,4
St. Domingo	109.2

Exceptionally heavy rainfalls are not, for our purpose, especially worthy of record; but it may be interesting to note, very briefly, the following instances reported by the U. S. Chief Signal Officer.*

A rain at Central City, Gilpin County, Cal., on August 8, 1881, caused a depth of water of from four to six feet in the main street.

At Wickenburg, Arizona, on August, 6, 1881, in five hours, a dry river-bed became a torrent, running ten miles per hour, a mile wide, and from two to fifteen feet deep.

At Rio Grande City, Texas, in May, 1885, in eleven hours, the Rio Grande River rose twenty feet, extending its width from one hundred yards to five miles.

A further list of very heavy rainfalls may be found in Rafter and Baker, "Sewage Disposal," page 134.

"Mr. R. de C. Ward (*Am. Met. Jour.*, March, 1892) states that in the memoirs of Benvenuto Cellini there is mention

* Senate Doc. 91, 50th Congress.

of the fact that an impending rain-storm was averted in the year 1539, on the occasion of a procession in Rome, by firing artillery in the direction of the clouds, which had already begun to drop their moisture. M. Arago, the eminent French astronomer, states that as early as 1769 it was the practice in certain towns in France to fire guns to break up storms, but he expressed doubt as to the effectiveness of that method. There have been numerous learned dissertations published by the scientists of Europe within the last two centuries relative to the possibility of breaking the force of storms by the use of explosives, and the question seems to have been settled by a negative conclusion.

In this country in recent years the question has assumed the opposite form, and the popular belief in the efficacy of explosives as rain-producers has stimulated scientific inquiry and led to some costly experiments under government auspices. The basis of this theory is the statement, which large numbers of people accept as true, that great battles have been generally, if not invariably, closely followed by storms.

This belief is deeply rooted in the popular mind, somewhat like the various notions held by many people in relation to the effects of the moon's phases upon the weather. And it appears to be a traditional idea, for the belief that battles cause rain was prevalent before the invention of gunpowder.

Plutarch says, "It is a matter of current observation that extraordinary rains generally fall after great battles"; and he accounts for it on the supposition that the vapors from blood steam forth and cause precipitation, or that the gods mercifully send rain to cleanse the earth from the stains of warfare.

While the question of rain-making by the use of explosives was under consideration at Washington the scientists of the Department of Agriculture made a thorough investigation of the subject, with all the records of the government at their command, and the conclusion reached was that there is no

foundation for the opinion that days of battle were followed by rain any more than days when it was all quiet along the lines.'' *

Regarding the relation of great fires to rainfall, Prof. I. A. Lapham, of the U. S. Signal Service, writes of the Chicago fire as follows:

"During all this time—twenty-four hours of conflagration upon the largest scale—no rain was seen to fall, nor did any fall until four o'clock the next morning; and this was not a very considerable downpour, but only a gentle rain that extended over a large district of country, differing in no respect from the usual rains. It was not until four days afterward that anything like a heavy rain occurred. It is, therefore, quite certain that this case cannot be referred to as an example of the production of rain by a great fire."

"As a result of a long study of the rainfall of India, and perhaps no country affords greater advantages for the purpose, I have become convinced that dynamic cooling, if not the sole cause of rain, is at all events the only cause of any importance, and that all the other causes so frequently appealed to in popular literature on the subject, such as the intermingling of warm and cold air, contact with cold mountain-slopes, etc., are either inoperative or relatively insignificant." †

As a further point it is well to note that while the air may rise into regions cooler than itself and become consequently chilled, a further cooling occurs by reason of the body of ascending air being expanded because of decreased pressure.

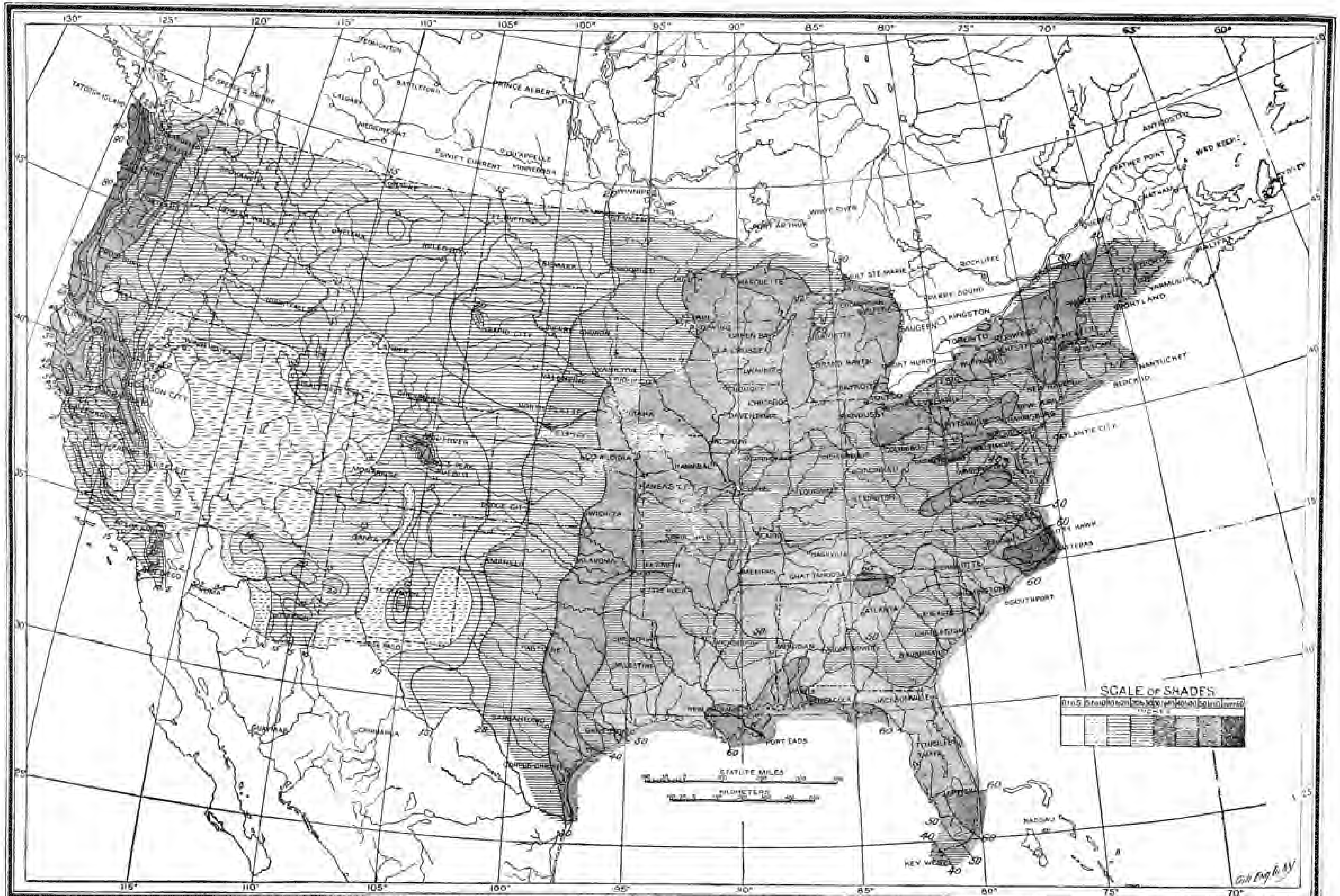
The following chart and statistics ‡ show the normal rainfall for the United States, and also the same data for separate States.

"In general, the rainfall decreases with the elevation above

* Sage, Iowa Weather and Crop Service.

† *Nature*, xxxix. 583.

‡ Report of the Chief of the U. S. Weather Bureau for 1891 and 1892.



AVERAGE YEARLY RAINFALL OF THE UNITED STATES.

RAINFALL AND SNOW OF THE UNITED STATES.

Annual and seasonal averages, seasonal variation and cubic miles for each State.

State.	Area in Square Miles.	Spring.	Summer.	Autumn.	Winter.	Annual.	Seasonal Variation.	Cubic Miles.
		Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	
Alabama	52,250	14.9	13.8	10.0	14.9	53.6	1.5	44.2
Arizona	113,020	1.3	4.3	2.2	3.1	10.9	3.3	19.4
Arkansas	53,850	14.3	12.5	11.0	12.8	50.6	3 9	42.5
California	158,360	6.2	0.3	3.5	11.9	21.9	40.0	54.9
Colorado	103,925	4.2	5.5	2.8	2.3	14.8	[illegible].4	24.2
Connecticut	4,990	11.1	12.5	11.7	11.5	46.8	1.1	3.6
Delaware	2,050	10.2	11.0	10.0	9.6	40.8	1.1	1.3
District of Columbia	70	11.0	12.4	9.4	9.0	41.8	1.4	0.04
Florida	58,680	10.2	21.4	14.2	9.1	54.9	2.4	51.0
Georgia	59,475	12.4	15.6	10.7	12.7	51.4	1.5	48.2
Idaho	84,800	4.4	2.1	3.6	7.0	17.1	3.3	22.7
Illinois	56,650	10.2	11.2	9.0	7.7	38.1	1.5	34.0
Indiana	36,350	11.0	11.7	9.7	10.3	42.7	1.2	24.2
Indian Territory	31,400	10.6	11.0	8.9	5.7	36.2	1.9	17.7
Iowa	56,025	8.3	12.4	8.1	4.1	32.9	3.0	28.8
Kansas	82,080	8.9	11.9	6.7	3.5	31.0	3.4	40.0
Kentucky	40,400	12.4	12.5	9.7	11.8	46.4	1.3	29.3
Louisiana	48,720	13.7	15.0	10.8	14.4	53.9	1.4	41.6
Maine	33,040	11.1	10.5	12.3	11.1	45.0	1.2	23.2
Maryland	12,210	11.4	12.4	10.7	9.5	44.0	1.3	8.3
Massachusetts	8,315	11.6	11.4	11.9	11.7	46.6	1.0	5.9
Michigan	58,915	7.9	9.7	9.2	7.0	33.8	1.4	31.3
Minnesota	83,365	6.5	10.8	5.8	3.1	26.2	3.5	34.4
Mississippi	46,810	14.9	12.6	10.1	15.4	53.0	1.5	38.8
Missouri	69,415	10.0	12.4	9.1	6.5	38.0	1.9	41.2
Montana	146,080	4.2	4.9	2.6	2.3	14.0	2.1	32.1
Nebraska	77,510	8.9	10.9	4.9	2.2	26.9	5.0	32.9
Nevada	110,700	2.3	0.8	1.3	3.2	7.6	4.0	14.4
New Hampshire	9,305	9.8	12.2	11.4	10.7	44.1	1.2	6.3
New Jersey	7,815	11.7	13.3	11.2	11.1	47.3	1.2	5.6
New Mexico	122,580	1.4	5.8	3.5	2.0	12.7	4.1	24.5
New York	49,170	8.5	10.4	9.7	7.9	36.5	1.3	28.3
North Carolina	52,250	12.9	16.6	12.0	12.2	53.7	1.4	44.2
North Dakota	70,795	4.6	8.0	2.8	1.7	17.1	4.7	19.1
Ohio	41,060	10.0	11.9	9.0	9.1	40.0	1.3	25.7
Oregon	96,030	9.8	2.7	10.5	21.0	44.0	7.8	66.7
Pennsylvania	45,215	10.3	12.7	10 0	9.5	42.5	1.3	30 2
Rhode Island	1,250	11.9	10.7	11.7	12.4	46.7	1.2	0.8
South Carolina	30,570	9.8	16.2	9.7	9.7	45.4	1.7	21.6
South Dakota	77,650	7.2	9.7	3.5	2.5	22 9	3.9	28.1
Tennessee	42,050	13.5	12.5	10.2	14.5	50.7	1.4	33.4
Texas	265,780	8.1	8.6	7.6	6.0	30.3	1.4	127.0
Utah	84,970	3.4	1.5	2.2	3.5	10.6	2.3	14.3
Vermont	9,565	9.2	12.2	11.4	9.3	42.1	1.3	6.1
Virginia	42,450	10.9	12.5	9.5	9.7	42.6	1.3	28.5
Washington	69,180	8.6	3.9	10.5	16.8	39.8	4.3	43.4
West Virginia	24,780	10.9	12.9	9.0	10.0	42.8	1.4	16.6
Wisconsin	56,040	7.8	11.6	7.8	5.2	32.5	2.2	28.7
Wyoming	97,890	4.3	3.5	2.2	1.6	11.6	2.7	17.9
Total	2,985,850	....	....	....	....	....	....	1407.14
Average	....	9.2	10.3	8.3	8.6	36.3	3.0	......

sea-level. This is very noticeable in passing along the parallel of latitude 40°.

"A very remarkable feature in the rainfall of the United States, appearing on most of the monthly maps, and distinctly on the annual map, is the way in which certain peaks and ranges of mountains are outlined by the mean rainfall.

"Another series of facts of very great interest can be read from the maps in the consideration of the relations of rainfall to the leeward and windward sides of the ranges. This is by far the best marked on the Pacific coast, where the prevailing winds are distinctly from the west and reach the coast laden with moisture from the warm ocean. To the westward, for instance, of the Sierra Nevadas on the annual map there is a rainfall of from 20 to 40 inches. Immediately to the eastward of this series of mountains the annual rainfall is only from 2 to 6 inches. Much the same is true of the Cascade Range, and even the Coast Range has a very marked influence on the rainfall. The annual line, for instance, of 40 inches of rainfall passes down the coast from Vancouver Island almost parallel to and westward of the Coast Range, although for most of this distance these mountains are quite low.

"Another curious fact which may be mentioned in connection with the general rainfall of the United States is that, generally, the great swampy areas occur in regions of highest rainfall. This is true, for instance, of the everglades of Florida, where the rainfall is from 50 to 70 inches per year. It is also true of the great swampy district lying on the coast of North Carolina, where the rainfall is 60 inches per year, and upward; also of the swampy district about the mouth of the Mississippi River; but is not so true of the celebrated swampy district lying to the west of the Mississippi along the Gulf coast.

"It is interesting to notice the effects of the Great Lakes on the rainfall visible on most of the maps. In general, it will be found that the rainfall is greater on the east shore of Lake

Michigan than on the west shore. It is to be noted that the prevailing winds here reach the lake from the west. Either they gather up considerable moisture from the lake which is deposited on the east shore, or, what is more probable, the temperature of the lake is such as to chill the air and cause it to deposit more of its moisture on the east shore than on the west. Much the same is true of the east shores of Lake Erie and Lake Ontario, areas which are small in both cases, because the lakes themselves lie east and west. There is, however, a distinct increase of rainfall along the southeastern coast of Lake Erie and to the east of Lake Ontario. These features can be traced on the monthly maps, but more perfectly on the seasonal ones. The effect seems to be somewhat more marked in the cold seasons than in the warm, and it is a noteworthy fact that the areas of deep snows in Michigan and New York are found to be on the same line. The area of deep snows for Southern Michigan is from the middle of the west coast, in the vicinity of Manistee, nearly straight across the peninsula; the area of deep snowfall in New York is to the eastward of Lake Ontario, and, to some degree, to the southward, in the immediate vicinity of the lake. It should also be noted that the area for deepest snow in the United States not mountainous is along the south shore of Lake Superior, from Marquette eastward. This would quite agree with the suggested influence of the lakes, in that the air passing over Lake Superior comes largely from the northwest, and by the time it reaches the coast in question has already received a surcharge of vapor chilled by the surface of this lake.

"Another interesting point is the average rainfall for the entire United States. The average of all stations, by States, gives for spring 9.2 inches, for summer 10.3 inches, for autumn 8.3 inches, and for winter 8.6 inches, and a total for the year of about 36 inches. It appears that the rainfall over the United States generally is quite evenly distributed through the

year, varying in total amount for the seasons from 10.3 for summer to 8.3 for autumn. The spring and summer rainfalls are the highest; other things being equal, the rainfalls of spring and, next to that, of summer are the most useful for agricultural operations.

"With the depth given it is not difficult to get the average total rainfall for the entire United States (excluding Alaska, where we have not sufficient information). For this purpose we may take the average for each State and multiply it by the area of the State, including water-surfaces. Adding these together we get 1407 cubic miles as the average annual total of water which descends as rain or snow in the United States. The figures for the areas are taken from the census of 1890. The annual depth of rainfall which this gives is 29 inches, or less than that given by the other method. This is to be expected, as the other method gave equal weight to each political division, and these divisions are generally smaller in the regions of greater rainfall.

"To get some conception of this enormous mass of water we may compare it with the contents of the Great Lakes, and an approximate comparison is near enough. Lake Ontario is about 200 miles long and 70 broad, and its average depth is about 40 fathoms. It therefore contains about 636 cubic miles of water. The annual rainfall would fill it two times and leave something over for a third time. Lake Michigan is about 310 by 70 miles and has an average depth of about 50 fathoms, and consequently contains about 1233 cubic miles of water. The average annual rainfall would fill Lake Michigan and leave 174 cubic miles over. Four years of rainfall would probably be enough to fill all the Great Lakes." (U. S. Weather Report.)

Reports published upon State authority at times do not agree with the United States returns above given. Thus the Weather Bureau of the State of New York places the average annual rainfall for that State at 37.50 inches.

The average annual rainfall for Massachusetts, as deduced from long-continued observations, is given by the State Board of Health as 45.15 inches.

Data for Connecticut, as published by its Board of Health, being averages for twenty years (1873–92), are:

January	4.39 inches
February	4.16 "
March	4.66 "
April	3.56 "
May	3.54 "
June	3.15 "
July	5.27 "
August	5.36 "
September	3.79 "
October	3.95 "
November	3.95 "
December	3.52 "
	49.30 inches

With a maximum of 60.26 inches in 1888, and a minimum of 37.78 inches in 1892.

Some observations were carried on at the weather station in Philadelphia in 1892 with a view to determine the effect, if any, of placing the rain-gauge at different elevations above the surface of the ground. (See table on page 248.)

"The results further confirm those taken in 1891, and prove plainly that there is no material difference between 50 feet elevation and the surface of the ground.

"Discrepancies will be found in gauges placed in positions where surrounding objects produce counter-currents of air.

"The tabulated results have been compared with those obtained from the gauge on the ground and the automatic gauge. The variations are caused by the wind acting upon the mast."

TABLE SHOWING OBSERVATIONS ON RAINFALL AT DIFFERENT ELEVATIONS ABOVE THE SURFACE OF THE GROUND.

Month.	Elevation Above the Ground in Feet.					
	0	5	10	15	25	50
January	4.44	3.71	3.62	3.57	3.62	3.54
February	1.04	0.87	1.06	0.99	0.94	1.14
March	5.06	4.45	4.47	4.14	4.34	3.96
April	2.40	2.36	2.45	2.40	2.11	2.43
May	5.68	5.45	5.45	5.52	5.25	5.92
June	2.31	2.30	2.28	2.14	2.20	2.52
July	3.38	2.89	3.19	3.14	3.19	3.25
August	3.25	3.10	3.15	3.13	3.08	3.14
September	2.47	2.23	2.33	2.27	2.13	2.43
October	0.37	0.35	0.34	0.36	0.33	0.37
November	6.81	5.94	6.66	6.98	6.58	6.81
December	2.14	1.76	1.90	2.06	1.88	1.95
Totals	39.35	35.41	36.90	36.70	35.65	37.46

SEVERE DROUGHTS IN THE MIDDLE STATES.*

"Mr. C. Warren furnishes the following from records giving the length of the most noted dry spells in the Middle States:

In the summer of 1634, 24 days.
In the summer of 1637, 74 days.
In the summer of 1642, 41 days.
In the summer of 1662, 80 days.
In the summer of 1664, 45 days.
In the summer of 1688, 81 days.
In the summer of 1694, 92 days.
In the summer of 1705, 30 days.
In the summer of 1715, 46 days.
In the summer of 1728, 61 days.
In the summer of 1730, 92 days.
In the summer of 1741, 72 days.
In the summer of 1745, 72 days.
In the summer of 1764, 108 days.
In the summer of 1755, 24 days.
In the summer of 1763, 133 days.
In the summer of 1773, 80 days.
In the summer of 1791, 82 days.
In the summer of 1812, 28 days.
In the summer of 1856, 26 days.
In the summer of 1871, 42 days.
In the summer of 1875, 26 days.
In the summer of 1876, 26 days.

"The longest drought above mentioned, which occurred in 1763, began on the first day of May, and many inhabitants of this country were compelled to send to Europe for grain and hay.

* Iowa Weather Service.

"It should be noted that the longest period of drought in the above records occurred over a century ago, at which time but little progress had been made in clearing the vast forests, draining the ponds, tilling the fields, and making that section of the country habitable for civilized man. A careful study of records covering all the years since the early settlement of this country does not disclose any appreciable decrease or increase in the seasonal precipitation, or in the temperature and humidity of the air." *

Evaporation measurements, both for land- and water-surfaces, have been conducted very carefully at certain points of the United States, and the results have been recorded by such competent observers as Desmond FitzGerald, W. J. McAlpine,† Professor Fuertes, T. Russell, and others. From the reports of these gentlemen and from other official sources the following data have been drawn.

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* SOME HISTORIC DROUGHTS.—"There have been droughts in all ages and countries. In the year 310 A.D. hardly a drop of water fell in England, and 40,000 people of famine.

"The seven years of drought and famine in Egypt, recorded in Genesis, began in the year 1708 B.C.

"In 954 a drought began in Europe, lasting four years. The summers were intensely hot and the famine prevailed everywhere; 3,000,000 died of hunger.

"In 1771 an unprecedented drought prevailed throughout India. Scarcely any rain fell for a year, and hundreds of thousands died of famine, whole districts being depopulated.

"In 1837 drought and intensely hot weather prevailed in Northwest India. Over 800,000 persons perished from famine. Similar destruction was wrought by the same causes in 1865 and 1866, over 2,000,000 persons perishing of hunger in the two years."

† Wm. J. McAlpine, in a report to the Water Committee of Brooklyn in 1852, finds "that from 30 to 40 per cent of the falling rain and snow is carried off by evaporation." The experiments were made by himself. In the same report the quotations are found as to the mean evaporation in inches at the following places:

Great Britain	32 inches per annum
Paris	38 " " "

TABLE SHOWING RELATION OF EVAPORATION TO RAINFALL (MASSACHUSETTS).

Month.	Average Year.			Year of Low Rainfall (1883).		
	Rainfall, Inches.	Evaporation, Inches.	Excess or Deficiency of Rainfall, Inches.	Rainfall, Inches.	Evaporation, Inches.	Excess or Deficiency of Rainfall, Inches.
January	4.18	0.98	+ 3.20	2.81	0.98	+ 1.83
February	4.06	1.01	+ 3.05	3.86	1.01	+ 2.85
March	4.58	1.45	+ 3.13	1.78	1.45	+ 0.33
April	3.32	2.39	+ 0.93	1.85	2.39	− 0.54
May	3.20	3.82	− 0.62	4.18	3.82	+ 0.36
June	2.99	5.34	− 2.35	2.40	5.34	− 2.94
July	3.78	6.21	− 2.43	2.68	6.21	− 3.53
August	4.23	5.97	− 1.74	0.74	5.97	− 5.23
September	3.23	4.86	− 1.63	1.52	4.86	− 3.34
October	4.41	3.47	+ 0.94	5.60	3.47	+ 2.13
November	4.11	2.24	+ 1.87	1.81	2.24	− 0.43
December	3.71	1.38	+ 2.33	3.55	1.38	+ 2.17
	45.80	39.12	+ 6.68	32.78	39.12	− 6.34

NOTE. + indicates excess of rainfall; − indicates deficiency.

In the year of low rainfall the evaporation was 6.34 inches greater than the rainfall. During the warmer months, from April to September inclusive, the excess of evaporation was 15.22 inches, and during the other six months the rainfall was 8.88 inches in excess of the evaporation. These figures indicate that a pond will not lower by evaporation in a dry summer more than about fifteen inches, even if it receives no water from its watershed.

Just determination of the rate of evaporation is a decidedly difficult problem to solve, for there exist so many disturbing factors which must be taken into consideration—such as direction and force of wind, character of soil, influence of crops, and such like matters—all of which tend to make the final result one of only very local application.

At Rothamsted, England, with an average annual rainfall of 31.04 inches, it was found that evaporation from bare soil

amounted to 17.09 inches, and that 13.95 inches percolated to a depth exceeding five feet, and appeared as drainage. Of these 13.95 inches of drainage 9.44 inches collected during five months, beginning in October, and the remaining seven months furnished only 4.51 inches, showing that the ground-water depends upon winter drainage for its principal reinforcement.*

"Evaporation from saturated woodland soil is from 61 to 63 per cent less than from saturated soil in the open, the rainfall in woodland commonly exceeding the evaporation, even in summer.

"Woldrich found that less water percolated in soil upon which grass was growing than upon a bare soil. Very light rains were wholly lost by evaporation from the grass. He also noted that when the snow melted in the spring the water from it passed from it into the bare land quicker and in larger quantity than it did into the soil that was grass-covered.

"According to Wollny, a calcareous loam which permitted 38 per cent of the rainfall to soak through when it was bare of vegetation percolated no more than 20 per cent of the rainfall when grass or clover was growing upon it.

"After extensive investigation it has been established that the rain which falls upon a crop during its growth is insufficient for its maintenance, and that such a crop would die were it cut off from drawing upon the reserve water stored up in the ground.

"About one quarter of a summer rainfall may cling to the leaves of trees and evaporate directly therefrom, while at the same time the trees act as pumping-engines to dry the ground, owing to evaporation from their enormous leaf-surface. Thus clay lands often become very wet after the cutting off of the trees." (Storer.)

* J. Chem. Soc., li. 504.

Johnson shows that filtration or percolation of water through two feet of soil in drain-gauges amounts to, in general, from 5 to 10 inches annually with a rainfall of from 26 to 44 inches.

The following is Risler's table of daily consumption of water for different crops, quoted in an article on irrigation by W. Tweeddale: *

	Inches.
Lucern grass	from 0.134 to 0.267
Meadow-grass	from 0.122 to 0.287
Oats	from 0.140 to 0.193
Indian corn	from 0.110 to 1.570
Clover	from 0.140 to . . .
Vineyard	from 0.035 to 0.031
Wheat	from 0.106 to 0.110
Rye	from 0.091 to . . .
Potatoes	from 0.038 to 0.055
Oak-trees	from 0.038 to 0.030
Fir-trees	from 0.020 to 0.043

Snyder gives similar data in a different form.† He places the average amount of water, in tons, required for the production of an average acre of various crops as follows:

Clover	400	tons	of water
Potatoes	400	"	"
Wheat	350	"	"
Oats	375	"	"
Peas	375	"	"
Corn	300	"	"
Grapes	375	"	"
Sunflowers	6000	"	"

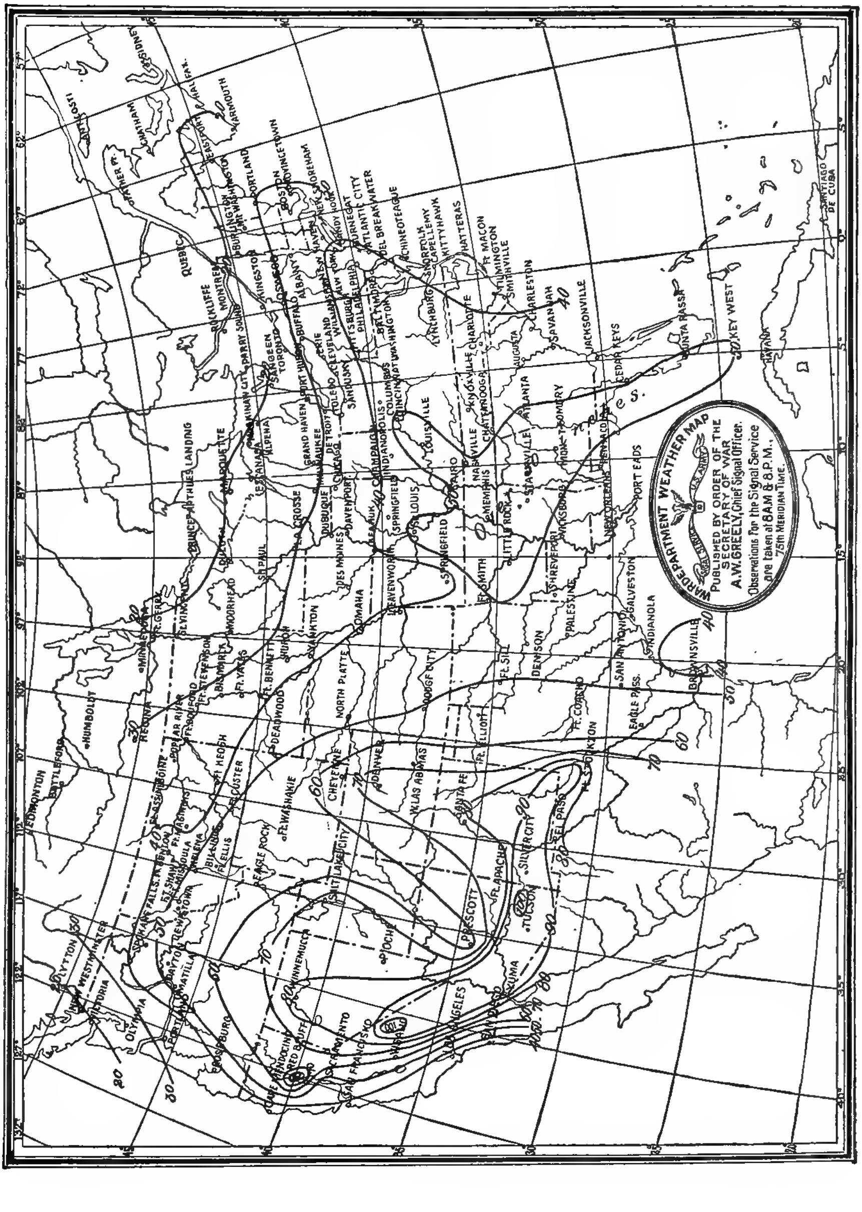
* Kansas State Board of Agriculture Report, December 31, 1889.
† Chemistry of Soils and Fertilizers, p. 25.

An average rainfall of two inches per month during the three months of crop-growth would be equivalent to 369 tons of water per acre.

M. Tweeddale concludes that "from seed-time to harvest cereals will take up fifteen inches of water, and grasses thirty-seven inches. These conclusions agree with practice in irrigation, and show plainly that the demands of plant-growth cannot be ignored in tracing the disappearance of rain. The figures also explain the low summer flow of streams flowing from a highly cultivated watershed. They do not necessarily explain the effect of forests in regulating flow, since many watersheds, although cleared of trees, are not put under cultivation, but still show some change in flow. The action of forests is probably largely to retard surface-flow by means of irregular surfaces, caused by roots, fallen timber, absorbent mosses, and leaf accumulation, thus holding the water until it can be taken into the ground. This is not mere theory; it is based on observations made during many days spent in the forest, and is believed to almost, if not fully, account for the better sustained flow of forest streams and their lighter flood-flows."

The official figures of the United States Weather Service will be found on pages 255 to 258.

"The daily evaporation from the surface of the United States has been generally assumed by engineers to be about 0.4 in. in 24 hours. But experiments prove that this may be doubled under certain conditions of dryness, temperature, and pressure; and at other times the evaporation may be negative; that is, moisture is actually added to the contents of the evaporation-gauge. What the resultant effect of these changes is no one can at present foresee; for the question has not been properly studied before for utilitarian purposes." (Fuertes.)



LINES OF EQUAL ANNUAL DEPTH OF EVAPORATION, IN INCHES. BASED ON OBSERVATIONS FROM JULY, 1887, TO JUNE, 1888, INCLUSIVE.

DEPTH OF EVAPORATION, IN INCHES, AT SIGNAL-SERVICE STATIONS, IN THERMOMETER SHELTERS.

Computed from the means of the tri-daily determinations of dew-point and wet-bulb observations.

Stations and Districts.	Jan., 1888.	Feb., 1888.	Mar., 1888.	April, 1888.	May, 1888.	June, 1888.	July, 1887.	Aug., 1887.	Sept., 1887.	Oct., 1887.	Nov., 1887.	Dec., 1887.	Year.
New England.													
Eastport	0.9	1.4	1.5	2.4	2.5	2.7	2.2	2.9	2.5	2.6	2.2	1.4	25.2
Portland	1.0	1.2	1.8	2.6	1.8	3.3	3.8	3.9	3.4	3.0	2.5	1.4	29.7
Manchester	0.9	1.6	2.2	3.3	3.8	5.0	4.1	3.3	2.5	2.8	2.4	1.4	33.3
Northfield	0.8	1.0	1.5	2.3	2.5	3.4	3.5	2.7	2.3	1.8	1.1	1.0	23.9
Boston	1.2	1.6	2.2	3.4	3.1	4.7	4.4	4.0	3.5	2.7	2.2	1.4	34.4
Nantucket	1.1	1.1	1.2	1.5	1.8	2.1	3.3	3.8	3.4	2.7	1.8	1.8	25.6
Wood's Holl	0.5	0.8	1.8	2.4	1.8	2.7	2.7	2.4	2.7	1.2	0.8	0.5	20.3
Block Island	1.1	1.1	1.2	2.0	1.8	2.6	2.5	3.1	2.8	2.6	1.8	1.4	24.0
New Haven	1.1	1.6	1.8	2.7	2.7	4.1	3.7	3.8	3.1	3.2	2.4	1.6	31.8
New London	1.5	1.3	1.5	2.6	2.8	4.0	3.4	3.9	3.2	3.1	2.4	2.1	31.8
Mid. Atlantic States.													
Albany	0.9	1.2	1.6	3.3	3.9	4.5	5.0	4.7	3.2	3.0	2.1	1.4	34.8
New York City	1.8	1.4	2.0	3.4	3.3	4.6	5.0	5.2	4.3	4.1	3.3	2.2	40.6
Philadelphia	1.6	2.1	2.5	4.4	4.0	5.7	5.7	5.2	4.3	4.0	3.3	2.2	45.0
Atlantic City	1.2	1.6	1.5	2.4	1.8	3.6	2.9	3.3	2.4	1.8	1.2	1.5	25.2
Baltimore	2.0	2.2	2.8	5.1	4.7	5.6	6.0	5.0	4.4	4.3	3.6	2.4	48.1
Washington City	1.8	1.7	2.5	4.2	3.8	6.0	5.4	4.9	4.1	4.2	4.5	2.5	45.6
Lynchburg	2.6	2.7	3.4	3.2	4.5	5.6	4.7	4.3	3.3	3.4	3.2	2.6	45.5
Norfolk	1.8	1.6	2.3	3.5	3.2	4.2	4.6	3.7	3.7	2.9	2.3	1.8	35.6
So. Atlantic States.													
Charlotte	2.6	2.6	4.3	0.4	4.5	5.8	4.0	4.0	4.6	4.0	3.6	2.6	49.0
Hatteras	1.8	1.6	1.6	2.5	2.2	3.0	3.3	4.1	3.8	3.2	2.6	1.6	31.3
Raleigh	2.0	1.8	2.6	3.8	4.1	5.4	4.2	3.2	3.0	2.7	2.4	1.8	37.0
Wilmington	2.4	2.2	2.7	3.3	3.3	4.3	4.3	3.1	3.9	3.4	2.8	2.7	38.4
Charleston	2.5	2.5	3.5	3.7	3.9	4.4	4.5	4.8	4.2	4.0	3.2	2.5	43.7
Columbia	2.2	2.3	2.6	4.8	4.3	5.4	4.2	3.8	4.2	3.4	3.6	2.4	43.2
Augusta	3.0	2.6	3.4	5.3	4.8	5.0	4.8	4.5	5.1	4.1	3.6	3.1	49.3
Savannah	3.3	2.8	4.1	4.7	4.3	4.6	4.2	4.7	3.4	3.6	3.5	2.8	46.0
Jacksonville	2.9	2.6	3.8	4.3	4.6	5.3	5.0	4.7	3.8	3.6	3.0	2.1	45.7
Florida Peninsula.													
Titusville	3.5	2.6	3.3	3.8	3.8	4.3	3.8	4.3	4.0	4.1	3.6	3.1	44.2
Cedar Keys	3.3	2.8	4.0	4.6	4.5	5.1	5.0	5.5	4.5	4.1	3.5	2.6	49.5
Key West	3.8	3.7	3.8	4.5	4.4	4.8	5.1	5.1	4.7	4.3	3.8	3.6	51.6
Eastern Gulf States.													
Atlanta	2.7	2.6	4.0	6.2	4.7	5.0	4.5	4.7	5.8	4.6	4.2	2.5	51.5
Pensacola	2.9	2.8	4.1	4.0	4.3	4.6	5.0	5.4	5.2	4.5	3.6	2.4	48.8
Mobile	2.6	2.5	2.8	3.5	3.7	4.0	4.1	4.6	4.6	4.1	3.4	2.2	42.1
Montgomery	3.5	3.3	5.1	6.5	5.9	5.8	4.3	4.5	5.7	4.6	4.3	3.1	56.6
Vicksburg	2.1	2.5	3.6	5.1	5.7	4.8	4.0	5.0	4.7	3.4	4.0	2.2	47.1
New Orleans	2.8	2.8	4.1	3.8	4.2	4.1	4.1	4.3	4.4	4.6	3.7	2.5	45.4
Western Gulf States													
Shreveport	1.6	2.1	3.0	4.8	4.9	4.2	4.9	5.2	5.0	4.1	3.4	2.4	45.6
Fort Smith	2.2	2.7	3.5	5.3	4.4	4.6	5.6	4.6	4.7	5.9	3.9	2.2	49.6
Little Rock	2.1	2.8	3.5	5.5	4.8	4.1	5.4	5.9	5.8	5.2	4.3	2.3	51.7
Corpus Christi	1.4	1.6	3.3	3.0	3.2	3.9	4.4	4.3	4.3	4.1	3.0	2.3	38.8
Galveston	1.6	2.8	3.2	2.9	4.3	4.2	5.3	5.2	5.2	4.7	4.2	2.4	46.0

DEPTH OF EVAPORATION, IN INCHES, AT SIGNAL-SERVICE STATIONS.—*Continued.*

Stations and Districts.	Jan., 1888.	Feb., 1888.	Mar., 1888	April, 1888.	May, 1888.	June, 1888.	July, 1887.	Aug., 1887.	Sept., 1887.	Oct., 1887.	Nov., 1887.	Dec., 1887.	Year.
Western Gulf States.													
Palestine	2.1	3.0	3.3	4.2	4.3	4.5	5.8	4.6	4.8	4.4	4.0	2.1	47.1
San Antonio	2.4	3.3	4.1	3.8	4.0	4.5	6.6	5.8	5.2	5.4	4.2	3.1	52.4
Rio Grande Valley.													
Rio Grande City	2.7	3.5	3.5	3.6	4.5	4.6	6.9	7.0	5.2	4.9	3.6	3.1	53.1
Brownsville	1.8	2.6	2.9	3.0	3.5	3.9	4.0	4.1	3.3	3.0	2.6	2.3	37.0
Ohio Val. & Tenn.													
Chattanooga	2.0	3.3	3.3	5.3	3.7	4.3	4.3	5.0	5.4	4.0	3.9	1.9	46.4
Knoxville	2.4	2.6	3.4	5.0	3.5	4.2	4.9	5.0	4.9	4.1	3.8	2.1	45.9
Memphis	2.1	2.3	3.1	5.9	5.3	4.8	4.9	5.4	5.5	4.2	4.1	2.4	50.0
Nashville	1.9	2.1	3.2	5.9	5.0	5.1	5.5	6.3	5.9	4.0	3.3	1.9	50.1
Louisville	1.7	2.1	2.8	5.6	5.4	5.8	6.8	7.4	6.4	4.9	3.8	2.1	54.8
Indianapolis	1.3	1.4	2.2	4.6	4.8	5.7	7.7	6.9	5.2	4.1	3.1	1.6	48.6
Cincinnati	1.8	1.8	2.6	4.9	5.2	6.4	6.5	6.6	6.1	4.7	3.3	2.1	52.0
Columbus	1.6	2.0	2.3	4.5	4.8	5.8	6.9	6.4	5.1	4.0	2.6	1.8	47.8
Pittsburg	1.4	1.9	2.2	3.8	4.2	5.4	6.6	5.6	4.9	3.4	2.8	2.3	44.5
Lower Lake Region.													
Buffalo	0.8	1.1	1.3	2.2	3.3	3.9	4.9	5.2	3.9	2.8	1.9	1.6	32.9
Oswego	0.6	1.0	1.1	2.2	2,8	3.8	3.9	4.0	3.6	2.7	2.2	1.0	28.9
Rochester	0.5	1.1	0.9	2.6	3.8	4.9	4.6	4.1	3.8	2.6	2.2	1.3	32.4
Erie	1.0	1.4	1.4	2.7	3.7	4.6	5.5	4.8	3.1	2.5	1.9	1.2	33.8
Cleveland	1.1	1.4	1.5	2.9	3.3	4.4	5.2	4.9	3.8	3.4	2.4	1.4	35.7
Sandusky	0.8	1.4	1.5	3.2	3.7	4.6	5.4	5.4	3.7	3.4	2.2	1.3	36.6
Toledo	0.9	1.1	1.5	3.5	3.8	4.6	6.0	6.4	3.7	3.4	2.4	1.3	38.6
Detroit	0.8	1.1	1.6	3.0	4.1	4.8	5.9	5.2	3.4	2.8	2.0	1.3	36.0
Upper Lake Region.													
Alpena	0.7	0.6	0.9	1.6	2.1	3.6	3.8	3.7	2.8	2.2	1.5	0.8	24.3
Grand Haven	0.5	0.7	1.3	2.6	3.1	3.8	4.7	3.8	2.7	2.6	1.7	1.1	28.6
Lansing	0.6	1.2	1.4	2.7	2.8	4.0	4.3	3.9	2.4	1.9	1.4	1.0	27.6
Marquette	0.8	0.8	0.9	1.7	2.4	3.3	3.4	3.3	3.1	2.2	1.3	1.3	24.5
Port Huron	0.6	1.0	1.1	2.6	3.0	3.8	4.6	4.2	3.2	2.5	1.7	1.0	29.3
Chicago	1.0	1.2	1.8	3.2	3.3	4.8	5.4	5.3	4.1	3.2	2.3	1.2	36.8
Milwaukee	0.5	1.0	1.1	2.4	2.6	3.8	4.8	3.7	3.4	2.9	1.9	0.9	29.0
Green Bay	0.5	0.6	0.8	1.7	2.5	4.1	5.6	4.2	3.0	2.4	1.9	0.9	28.2
Duluth	0.5	0.5	0.6	1.5	2.4	2.5	3.9	3.4	3.0	2.5	1.2	1.0	23.0
Extreme Northwest.													
Moorhead	0.2	1.4	0.5	2.1	3.6	3.8	3.7	3.3	3.5	2.4	1.3	0.5	26.3
Saint Vincent	0.3	0.3	0.5	1.8	3.8	3.9	3.1	2.6	2.6	2.0	0.9	0.3	22.1
Bismarck	0.4	0.6	0.6	3.0	4.3	4.1	5.6	4.2	4.0	2.6	1.2	0.4	31.0
Fort Buford	1.4	0.7	0.6	3.0	4.7	5.0	6.2	4.9	4.8	3.0	1.7	0.5	35.5
Fort Totten	0.2	0.3	0.4	2.2	4.6	3.8	4.2	3.7	3.7	2.3	1.4	0.4	27.2
Up. Mississippi Val.													
Saint Paul	0.7	0.7	2.2	2.0	2.3	4.1	5.0	3.7	2.8	2.4	1.5	0.7	28.1
La Crosse	0.4	1.2	1.4	3.3	3.5	4.4	5.4	4.7	3.0	3.0	1.8	0.8	32.9
Davenport	0.5	1.0	1.8	3.8	3.4	4.6	6.9	6.2	4.4	3.0	2.3	1.1	39.0
Des Moines	0.6	1.0	1.5	3.7	3.1	4.2	6.6	4.7	4.1	3.3	2.3	0.9	36.0
Dubuque	0.7	1.0	1.4	2.2	2.9	4.2	6.2	4.8	3.3	2.8	1.8	0.9	33.2
Keokuk	0.8	1.1	2.1	4.2	3.7	4.3	7.0	6.8	5.0	3.8	2.9	1.2	42.9
Cairo	1.6	2.1	2.9	5.8	4.4	4.3	5.6	6.5	5.1	4.5	3.8	2.3	48.9
Springfield, Ill.	0.8	1.1	2.0	4.6	3.8	4.3	5.4	6.5	4.5	3.5	2.9	1.4	40.8
Saint Louis	1.3	1.6	2.5	5.5	4.7	5.0	7.5	8.0	5.9	4.9	3.9	1.4	52.2

DEPTH OF EVAPORATION, IN INCHES, AT SIGNAL-SERVICE STATIONS—*Continued.*

Stations and Districts.	Jan., 1888.	Feb., 1888.	Mar., 1888.	April, 1888.	May, 1888.	June, 1888.	July, 1887.	Aug., 1887.	Sept. 1887.	Oct., 1887.	Nov., 1887.	Dec., 1887.	Year.
Missouri Valley.													
Lamar	1.1	1.6	2.4	4.4	3.8	4.0	6.0	4.6	3 7	3.6	2.9	1.5	39.6
Springfield, Mo.	1.1	1.7	2.4	5.0	4.8	4.0	5.0	3.4	3 4	3.5	3.1	1.4	38.3
Leavenworth	0.9	1.5	2.3	4.6	4.5	5 0	6.3	4.5	4.0	3.9	2.7	1.4	41.6
Topeka	1.1	1.2	2.0	4.0	4.1	4.1	6.3	3.5	3.2	3.0	2.2	1.4	36.1
Omaha	0.8	1.5	1.4	4.4	3.8	5.2	6.2	5.2	4.3	4.3	3.0	1.4	41.7
Crete	0.7	1.1	1.2	3.5	3.3	4.5	5.6	4.7	3.8	3.6	2.4	1.1	35.5
Valentine	1.2	1.6	1.8	5.0	3.2	5.3	6.9	5.0	5.2	3.8	3.3	1.5	43.8
Fort Sully	0.6	0.9	1.3	4.4	4.1	5.2	7.7	4.9	5.7	3.6	2.8	0.7	41.9
Huron	0.3	0.7	0.8	3.7	3.7	4.1	5.7	4.2	4.1	3.1	2.4	0.7	33.0
Yankton	0.4	1.4	1.2	3.3	3.1	4.4	4.6	3.7	2.9	3.0	2.2	0.8	31.0
Northern Slope.													
Fort Assiniboine	0.8	1.2	1.2	3.8	4.1	4.2	6.8	5.5	4.8	3.5	2.5	1.1	39.5
Fort Custer	0.6	1.5	1.3	5.4	6 8	4.9	9.6	8.0	6.1	3.4	2.9	1.5	52.0
Fort Maginnis	1.1	1.4	1.1	3.3	3.2	4.6	6.8	4.6	3 8	2.8	2.0	1.1	35.8
Helena	1.1	3.6	2.1	6.1	4.3	5.5	7.2	7.7	6.4	4.3	3 0	2.1	53.4
Poplar River	0.4	0.8	0.8	2.7	4.9	5.7	6.0	4.8	4.4	2.5	1 7	0.7	35.4
Cheyenne	3.3	5.7	4.0	8.2	5.2	10.4	8.0	7.7	8.6	5.8	6.1	3.5	76.5
North Platte	0.8	1.8	1.8	5.4	3.9	6.9	6.0	4.8	3.7	2.8	2.3	1.1	41.3
Middle Slope.													
Colorado Springs	3.0	3.3	4.1	6.7	5.6	4.3	6.7	7.2	6.8	4.6	4.2	2.9	59 4
Denver	2.8	3.7	3.5	7.6	5.8	10 5	8.3	8.5	6.1	4.9	4.2	3.1	69.0
Pike's Peak	2.1	1.3	1.5	2.1	1.8	1.9	3.0	4.0	3.0	2.3	2.8	1.0	26.8
Concordia	1.3	2.8	1.8	4.8	4.3	5.7	7.3	5.2	4.3	4.5	3.4	1.8	47.2
Dodge City	1.4	2.4	2.8	4.1	4.6	7.4	8.3	6.6	5.5	5.2	4.2	2.1	54.6
Fort Elliott	1.3	1.9	3.2	5.1	5.4	8.2	7.6	6.2	5.4	4.7	4.2	2.2	55.4
Southern Slope.													
Fort Sill	1.6	2.0	2.6	3.8	4.0	4.4	4.8	7.5	5.1	4.2	4.1	2.0	46.1
Abilene	1.8	1.7	3.1	4.2	5.0	5.8	9.5	7.5	6.2	4.5	3.4	1.7	54.4
Fort Davis	5.4	5.7	6.7	8.5	11.0	12.0	11.4	9.0	5.9	5.2	5.7	4.9	96.4
Fort Stanton	3.9	3.9	5.2	7.3	9.5	10.9	9.4	11.6	3.9	4.0	3.6	3.8	76.0
Southern Plateau.													
El Paso	4.0	3.9	6.0	8.4	10.7	13.6	9.4	7.7	5.6	5.2	4.6	2.9	82.0
Santa Fé	3.0	3.4	4.2	6.8	8.8	12.9	9.2	9.8	6.6	6.7	5.7	2.7	79.8
Fort Apache	2.6	3.0	3 6	6.8	9.4	9.1	7.1	6.7	5.3	5.2	4.1	2.6	65.5
Fort Grant	5.2	4.8	6.4	9.2	10.2	13.8	12.4	10.5	9.0	7.9	7.2	4.6	101.2
Prescott	1.4	2.8	3.6	5.4	6.2	8.1	6.6	6.5	4.7	4.9	3.6	2.2	56.0
Yuma	4.4	5.2	6.6	9.6	9.6	12.6	11.0	10.2	8.2	8.2	5.5	4.6	95.7
Keeler	3.0	4.6	6.3	8.7	9.3	11.9	12.8	13.9	10.6	8.8	5.9	4.8	100.6
Middle Plateau.													
Fort Bidwell	0.8	1.8	1.8	4.6	5.2	4.0	8.8	8.1	5.0	4.6	2.4	1.3	48.9
Winnemucca	0.9	2.8	6.2	9.1	9.3	10.1	11.5	12.0	9.9	6.6	3.7	1.8	83.9
Salt Lake City	1.8	2.7	3.6	7.2	6.9	8.9	9.2	10.7	9.6	6.5	5.0	2.3	74.4
Montrose	1.8	2.7	3.7	6.2	7.0	11.1	10.2	8 3	6.9	5.2	3.4	2.0	68.3
Fort Bridger	1.6	2.5	2.7	4.3	4.3	6.5	7.7	6.8	5.6	4.2	5.2	4.7	56.1
Northern Plateau.													
Boisé City	1.6	2.5	3.8	6.1	6.5	6.6	10.0	9.2	7.4	5.2	3.2	1.8	63.9
Spokane Falls	0.7	1.7	2.7	4.4	5.4	4.4	7.7	6.4	3.8	2.5	1.7	1.4	42.8
Walla Walla	1.1	2.9	3.6	6.2	7.7	5.7	9.9	7.9	5.1	3.4	1.8	2.4	57.7
North Pacific Coast.													
Fort Canby	1.2	1.1	1.8	2.1	2.8	2.3	1.8	2.9	1.8	1.8	1.5	0.9	21.1

DEPTH OF EVAPORATION, IN INCHES, AT SIGNAL-SERVICE STATIONS—*Continued.*

Stations and Districts.	Jan., 1888.	Feb., 1888.	Mar., 1888.	April, 1888	May, 1888.	June, 1888.	July, 1887.	Aug., 1887.	Sept., 1887.	Oct., 1887.	Nov., 1887.	Dec., 1887.	Year.
North Pacific Coast.													
Olympia..........	1.3	1.2	1.8	2.5	4.1	3.3	3.2	3.1	2.4	1.5	1.3	1.1	26.8
Port Angeles......	1.0	0.9	1.8	1.8	2.5	2.1	2.1	1.8	1.5	1.2	1.3	1.1	19.1
Tatoosh Island....	1.2	1.1	1.8	1.4	1.8	1.8	1.4	1.4	1.4	1.6	1.8	1.4	18.1
Astoria............	1.1	1.0	1.6	2.1	3.0	2.7	3.0	2.9	2.6	2.3	1.8	1.2	25.3
Portland..........	0.9	1.1	2.4	3.4	5.0	3.2	5.4	4.2	3.4	2.7	1.8	1.2	34.7
Roseburg..........	1.2	1.6	2.7	3.9	4.7	3.5	5.4	4.7	5.0	3.2	1.7	1.6	39.2
Middle Pacific Coast													
Red Bluff.........	3.0	4.6	5.4	6.1	7.0	6.9	11.0	10.7	10.1	10.5	5.9	3.6	84.8
Sacramento.......	1.8	3.1	3.7	4.3	4.2	5.6	5.9	5.6	6.5	7.3	3.9	2.4	54.3
San Francisco.....	2.7	2.7	3.3	3.1	2.8	3.1	2.4	2.5	3.3	5.0	2.8	3.0	36.7
South Pacific Coast.													
Fresno............	1.8	2.8	3.0	5.6	6.0	7.0	9.1	10.2	7.6	6.7	3.8	2.2	65.8
Los Angeles.......	2.3	2.0	2.8	3.4	3.0	3.8	3.2	3.5	3.1	4.1	3.0	3.0	37.2
San Diego	2.9	2.7	2.5	2.7	3.3	2.8	3.2	3.3	2.9	4.3	3.2	3.7	37.5

The flow of streams depends upon causes quite various in character, such as deep-seated springs, melting of glaciers (e.g., the River Rhone), and other like unusual sources, but for the great majority of cases the flow is traceable directly to the rainfall and to springs of local origin.

What is the amount of the "run-off" to be expected per square mile of watershed is essentially an engineering question, not to be considered here beyond stating the views of some prominent authorities.

Fanning believes that for ordinary watersheds it is fair to assume that 50 per cent of the annual rainfall flows off in the streams.

More in detail, it is as follows:

Mountain slope or steep rocky hills........	80 to 90 per cent
Wooded swampy lands........	60 " 80 " "
Undulating pasture and woodland.........	50 " 70 " "
Flat cultivated lands and prairie..........	45 " 60 " "

He also considers the "low rain-cycles" mean rainfall to be about 80 per cent of the general mean rainfall.

According to the U. S. government reports, "for the area of the United States east of the ninety-fifth meridian the run-off is from 35 to 50 per cent of the total rainfall. It appears to be largest in the vicinity of the Great Lakes, and diminishes from this region slowly to south and east, and rapidly towards the west. In the lower peninsula of Michigan, for instance, the run-off is 50 per cent of the total rainfall. Along the Gulf coast it appears to be only from 30 to 40 per cent, and along the Atlantic coast it probably varies from 30 to about 50 per cent. In general, for the interior States east of the ninety-fifth meridian the run-off is between 40 and 50 per cent of the total rainfall.

"As soon as we cross the ninety-fifth meridian westward we find a very sharp fall in the percentage of run-off to the total rainfall. For the band extending north and south between the ninety-fifth and one hundred and fifth meridians this percentage varies from 10 to 25 per cent, and over Iowa is about 33 per cent. The percentage is highest at the northern end of the band indicated, and lowest at the southern end. Going still farther westward we come to another very marked area, that of the Continental Divide; here the percentage of run-off suddenly increases, reaching the highest figure to be found in the United States. From Montana to Colorado it varies from 60 to 70 per cent of the total rainfall. In New Mexico it falls to about 33 per cent. This is evidently on account of the easy flow of water from the mountain ranges in the area in question. West of the Divide the run-off is again small, being only 15 or 20 per cent in Arizona and Nevada, about 30 per cent in Idaho, and nearly 50 per cent in Utah. Utah, it seems from its topography, partakes of the character of the band lying just to the east of it. Along the Pacific coast the run-off is about 25 per cent in Oregon, 30 per cent in Washington, and between 45 and 50 per cent in California.

"In general we may say that the run-off on the more level areas of the United States is less than 50 per cent, and on the great plains may fall as low as 10 per cent. In the mountain regions it may rise to as high as 70 per cent. In the relatively dry areas, or the areas of distinctly dry seasons, the percentage is very much reduced."* The "run-off" for the State of Connecticut is placed at sixty per cent of the rainfall.

Since about half the rainfall is to be counted as "run-off" on ordinary watersheds and only about fifty per cent of such "run-off" can be successfully stored for use, we should have, with forty-eight inches of rainfall, only from twelve to fifteen inches for storage. Placing twenty-four inches of rainfall as about equal to one million gallons per square mile per day, we thus find that the probable daily yield for storage purposes per square mile would be about half a million gallons.

The following figures have been collected from various official sources, some of them having been prepared by C. C. Babb, of the U. S. Geological Survey:

RAINFALL AND RIVER-FLOW FOR THE CONNECTICUT RIVER BASIN, AVERAGES FOR 13 YEARS, 1871–85.

Month.	Average Rain in Inches.	River-flow in Inches on Whole Watershed.	Per Cent of River-flow to Rainfall.
January	3.27	1.93	59.1
February	3.10	2.04	65.8
March	3.94	3.00	76.3
April	3.26	4.73	145.0
May	3.17	4.19	132.2
June	4.00	1.46	36.5
July	4.79	1.02	21.3
August	4.87	1.06	21.8
September	3.04	0.89	29 3
October	3.93	1.11	28.3
November	3 93	1.76	44.8
December	3.39	2.06	60 7
	44.69	25.25	56.5

* "The point at which a region may be classed as arid and unfit for successful agriculture without irrigation should be lowered, it is believed, to 15 inches annual rainfall." (Report of Chief Signal Officer, 1889.)

RAINFALL AND RIVER-FLOW FOR SUDBURY RIVER (MASS.) WATERSHED, MEAN FOR 18 YEARS, 1875–92 INCLUSIVE.

Month.	Rainfall in Inches	River-flow in Inches on Watershed.	Per Cent of River-flow to Rainfall.
January	4.430	2.307	52.08
February	4.076	3.223	79.07
March	4.055	5.097	109.49
April	3.214	3.533	109.93
May	3.269	1.957	59.87
June	3.016	0.853	28.28
July	3.788	0.335	8.84
August	4.266	0.534	12.52
September	3.163	0.450	14.23
October	4.200	0.938	22.33
November	4.144	1.537	37.09
December	3.565	1.833	51.42
	45.786	22.599	49.36

AVERAGES FOR THE SAVANNAH BASIN DURING 8 YEARS, 1884–92.

Month.	Rainfall in Inches.	River-flow in Inches.	Per Cent of River-flow to Rainfall.
January	4.34	2.50	57.6
February	3.47	2.59	74.6
March	4.86	3.13	64.4
April	2.08	1.99	95.7
May	4.05	1.51	37.3
June	4.44	1.41	31.8
July	6.46	1.47	22.8
August	4.59	1.96	42.7
September	3.70	1.73	46.8
October	3.03	1.26	41.6
November	1.68	1.33	79.1
December	2.71	1.31	48.1
	45.41	22.19	48.9

AVERAGES FOR THE POTOMAC BASIN DURING 6 YEARS, 1886–92.

Month.	Rainfall in Inches.	River-flow in Inches.	Per Cent of River-flow to Rainfall.
January	3.21	2.09	65.2
February	3.35	3.36	100.1
March	4.39	3.62	82.6
April	3.48	3.51	101.0
May	5.11	2.36	46.3
June	5.25	1.93	36.8
July	4.89	1.00	20.5
August	3.81	0.78	20.5
September	3.86	1.06	27.5
October	2.65	1.21	45.7
November	2.88	1.79	62.3
December	2.59	1.32	51.1
	45.47	24.03	53.0

AVERAGES FOR THE NESHAMINY (PA.) BASIN DURING 7 YEARS, 1884–91.

Month.	Rainfall in Inches.	River-flow in Inches.	Per Cent of River-flow to Rainfall.
January	4.28	3.98	93.1
February	4.42	4.22	95.2
March	3.88	3.51	90.5
April	3.06	2.19	71.6
May	3.75	1.03	27.6
June	4.31	0.75	17.4
July	6.05	1.34	22.2
August	4.91	1.35	27.5
September	3.88	1.18	30.4
October	4.04	1.34	33.2
November	3.84	1.73	45.1
December	3.78	2.56	67.8
	50.20	25.18	50.1

AVERAGES FOR THE CROTON (N. Y.) BASIN DURING 14 YEARS. (BABB.)

Month.	Rainfall in Inches.	River-flow in Inches.	Per Cent of River-flow to Rainfall
January	3.65	2.12	58.2
February	3.30	2.47	74.9
March	4.36	3.80	89.6
April	3.64	3.51	96 5
May	3.28	2.44	74.4
June	3.66	1.06	29 0
July	3.92	0.60	15.3
August	3.76	1.05	28.0
September	4.00	0.93	23.3
October	4.00	1.01	25.3
November	3.98	1.33	33.4
December	3.53	2.04	57.8
	45.08	22.30	49.6

These figures for the Croton watershed are slightly different from those given by the New York State Board of Health, which latter cover a period of twenty-one years, 1870–90 inclusive, and are as follows:

Average yearly rainfall	48.37 inches
Average yearly river-flow	24.52 "
Per cent of river-flow to rainfall	50.70 "

A good map showing the "run-off" for the United States will be found in the 14th report of the U. S. Geological Survey, Part II, page 150.

Even with uniformity in rainfall the rate of river-flow must vary, owing to such disturbing factors as frozen ground in winter and excessive evaporation in summer.

For Eastern Massachusetts Mr. Desmond FitzGerald places the months in order of dryness, averaging as follows:

1. July.	4. June.	7. May.	10. April.
2. September.	5. October.	8. December.	11. February.
3. August.	6. November.	9. January.	12. March.

howing the wettest months to be the first four in the year.

INFLUENCE OF FORESTS UPON WATER-SUPPLY.

The following is freely condensed and extracted from the government report upon "Forest Influences," issued by B. E. Fernow, Chief of the Forestry Division.

The liability of forests to increase the actual annual precipitation is yet in discussion, but numerous data are available tending to show that such increase occurs.

Field Station.			Compared with Average over Open Regions.		
Name.	Elevation.	Mean Annual Precipitation.	Name.	Mean Annual Precipitation.	Surplus over Woods.
	Feet.	Inches.		Inches.	Inches.
Schoo	10	28.4	North Sea coast	27.5	+ 0.5
Eberswalde	77	21.9	Brandenburg	21.8	+ 0.1
Fritzen	98	25.6	East Prussia	24.1	+ 1.5
Hadersleben	112	30.1	Baltic coast	26.0	+ 4.1
Lintzel	312	23.3	Hanover	26.9	− 3.6
Kurwien	407	24.5	East Prussia	24.1	+ 0.4
Marienthal	469	22.5	Thüringen and Saxon provinces.	23.2	− 0.7
Hagenau	500	31.6	Alsace-Lorraine	30.4	+ 1.2
Neumath	1159	32.3	"	30.4	+ 1.9
Friedrichsrode	1158	26.5	Thüringen and Saxon provinces	23.2	+ 3.3
Lahnhof	1975	44.2	Westphalia	30.7	+14.5
Hollerath	2005	38.3	Rhine country	25.6	+12.7
Schneidefeld	2230	50.2	Thüringen and Saxon provinces.	23.2	+27.0
Carlsberg	2400	38.9	Silesian Mountains	27.2	+11.5
Sonnenberg	2549	55.5	Harz	36.4	+19.1
Melkerei	3071	69.9	Alsace-Lorraine	30.4	+39.5

It seems from this that where the results at the stations near forests are compared with the general results in the section of country in which the station is situated the forest station usually shows more rainfall. Lintzel is exceptional, because near young trees on an exposed moor.

Altogether the question of appreciable forest influence upon precipitation must be considered as still unsolved, with some indications, however, of its existence under certain climatic and topographical conditions in the temperature zone, especially toward the end of winter and beginning of spring.

Other observers take exception to the suggestions advanced by Fernow and hold that however much forested areas may affect stream-flow, they do not do so by increasing the annual rainfall.

A very considerable part of the water falling as rain upon a forest is returned to the atmosphere by transpiration through the leaves. It must be remembered, however, that the smaller vegetables also pump water out of the soil in a similar fashion, often more rapidly, per acre, than the forest trees.

During the period of vegetation the following varieties transpired per pound dry weight of leaves:

	Pounds of Water.
Birch and linden	600–700
Ash	500–600
Beech	450–500
Maple	400–450
Oaks	200–300
Spruce and Scotch pine	50–70
Fir	30–40
Black pine	30–40

Conifers transpire one sixth to one tenth of the amount which is needed by deciduous trees.

The transpiration from leaves in full sunshine is decidedly greater than from leaves in the diffused daylight or darkness. The absolute amount of annual transpiration as observed in forests of mature oaks and beeches in Central Europe is about one quarter of the total annual precipitation.

Evaporation in the forest is naturally much less than in the open fields.

The forest cover, and especially the litter of a well-kept forest, may decrease the amount of evaporation within the

forest to nearly seven eighths of that in the open. The reason for this important influence of the forest is due not only to the impeded air circulation, but also to the temperature and moisture conditions of the forest air and forest soil.

EVAPORATION IN WOODS IN PER CENT OF EVAPORATION IN THE OPEN.

	Dr. Ebermayer's Results.						German Observations.		
	Water-surface.		Bare Soil.		Soil under Forest Litter and within Forest.	Rainfall.	Water-surface.		Rainfall.
	Open.	Woods.	Open.	Woods.			Open.	Woods.	
April	1	.45	1.15	.64	.27	1.75	1	.51	1.37
May	1	.43	.91	.37	.16	.68	1	.47	1.35
June	1	.36	1.07	.38	.14	1.46	1	.41	1.91
July	1	.35	.89	.34	.12	1.02	1	.38	2.33
August	1	.34	.87	.36	.11	1.00	1	.36	1.98
September	1	.33	.92	.39	.11	.59	1	.35	2.54
October	1	.41	1.26	.44	.18	3.45	1	.37	8.49
May–Sept.	1	.36	.93	.35	.13	.95	1	.39	2.02

The stations of Prussia allow the following average for evaporation, the amount evaporated in the open fallow field being called 100:

	Evaporated.	Retained More than in Open Fallow Field.
	Per Cent.	Per Cent.
Under beech growth	40.4	59.6
Under spruce growth	45.3	54.7
Under pine growth	41.8	58.2
From cultivated field	90.3	9.7

It is this protection against evaporation which gives to the forest its chief value as a guardian of water-supply. The forest floor, with its irregularities and its sponge-like qualities, moreover, stops the rapid and ruinous draining of the surface, with attendant denuding of the land, and favors slow percolation through the soil and reinforcement of the springs.

The New York Forest Commission, speaking of floods in the Adirondack region and the influence of forests in relation to them, say:

"In the uplands of the preserve there are many densely wooded tracts adjacent to others from which the forests have been stripped. The residents agree that in the former floods are unknown, while in the latter they are a yearly occurrence. Their appearance was coincident with the disappearance of the woods. It was then noticed that the bridges, which for many years had sufficed to span the streams during heavy rains, were no longer safe, and new ones with longer spans became a necessity."

They refer also to the effect of the removal of the forests in the Adirondack watersheds upon the navigation of the canals of the State and the whole system of inland commerce. They say:

"With the clearing away of the forests and the burning of the forest floor came a failure of canal supply that necessitated the building of costly dams and reservoirs to replace the natural ones which the fire and axe had destroyed. The Mohawk River, which for years had fed the Erie Canal at Rome, failed to yield any longer a sufficient supply, whereupon the Black River was tapped at Forestport, and its whole volume at that point diverted southward to assist the Mohawk in its work."

In consequence of deforestation evaporation from the soil is augmented and accelerated, resulting in unfavorable conditions of soil humidity and affecting unfavorably the size and continuity of springs. The influence of forest cover upon the flow of springs is due to this reduced evaporation, as well as to the fact that by the protecting forest cover the soil is kept granular and allows more water to penetrate and percolate than would otherwise be the case. In this connection, however, it is the condition of the forest floor that is of greatest

importance. Where the litter and humus mould is burned up, as in many, if not most, of our mountain forests, this favorable influence is largely destroyed although the trees are still standing.

Snow is held longer in the forest and its melting is retarded, giving longer time for filtration into the ground, which also, being frozen to lesser depth, is more apt to be open for subterranean drainage. Altogether forest conditions favor, in general, larger subterranean and less surface drainage, yet the moss or litter of the forest floor retains a large part of the precipitation and prevents its filtration to the soil, and thus may diminish the supply to springs. This is especially possible with small precipitations.

Although the quantity of water offered for drainage on naked soil is larger, and although much is utilized by the trees in the process of growth, yet the influence of the soil-cover in retarding evaporation is liable to offset this loss, as the soil-cover is not itself dried out.

The surface drainage is retarded by the uneven forest floor more than by any other kind of soil-cover. Small precipitations are apt to be prevented from running off superficially through absorption by the forest floor. In case of heavy rainfalls this mechanical retardation in connection with greater subterranean drainage may reduce the danger from freshets by preventing the rapid collection into runs.

The temporary retention of large amounts of water and eventual change into subterranean drainage which the well-kept forest floor produces, the consequent lengthening in the time of flow, and especially the prevention of accumulation and carrying of soil and detritus which are deposited in the river and change its bed, would at least tend to alleviate the dangers from abnormal floods and reduce the number and height of regular floods.

In short, the forest acts as a "governor" of stream-flow, rather than as a means of increasing precipitation.

Having once carefully selected a watershed, it should be protected with the greatest care which science suggests, and with the utmost vigor which the law allows. Right here is the weakness shown by many of our city councils. The law is strong enough, and the municipal rights are plenty, but it is often very difficult to move the authorities to proper action. The most fruitful source of evil arises from the unquestioned right of a riparian landholder to "water his stock." The broad interpretation of this right can be carried to an absurd degree; for instance, the writer has seen the open channelway connecting the storage- and distributing-reservoirs of a large city doing duty, at one point of its course, as a farmyard drain, the cattle standing in the small stream at pleasure.

It may not be amiss here to point out that regulations for the protection of a watershed which do well enough during summer months may entirely fail of effectiveness after the ground becomes frozen. Drainage material which at one time could sink into the ground and become oxidized by infiltration would at other seasons flow down steep slopes over the frozen surface, or, if itself arrested by frost, would be at a later date washed into the stream by melting snows over the yet unthawed ground. Such cases of contamination are not rare, and may be followed by most serious consequences, as was instanced by the outbreak of typhoid fever at Plymouth, Pa. It is useless to depend upon the purifying action of frost, for, as has been shown, typhoid germs can withstand being frozen in solid ice during a period of months.

To repeat what we have already touched upon, the purifying action of filtration through common soil is another point frequently misunderstood, and yet of important bearing when

considering the protection of a watershed. Such filtration is only effective when it is intermittent.

The nitrifying organism which accomplishes the oxidation of the objectionable sewage material can only operate in presence of atmospheric oxygen. A supply of air must be present in the pores of the soil or else purification ceases. After a "dose" of sewage has been applied to a soil a sufficient interval must elapse to permit the air to renew the exhausted oxygen; otherwise the slow-moving and continuous stream of filth must carry its objectionable properties to considerable distances.

How important, then, that every privy located within drainage distance of a source of water-supply should be built without a vault, and should have its cleanings removed at frequent intervals and applied to successive pieces of ground!

However desirable for the moment a river may be as a source of water-supply, it must not be forgotten that the conditions may change in the course of years with the growth of population up-stream, as has been already noted on another page. Objection was recently raised by the writer to the future use of the unfiltered water of a large river, on the ground that pollution of the stream by sewage material is certainly on the increase, and that the introduction of sewerage systems in the towns above will, at no distant date, render the river-water very undesirable. A small mountain brook was recommended instead. The local critics objected by saying:

"The assumed pollution of the water of the river by human occupancy upon its banks above the intake, in the light of modern science, cannot possibly be so great as it must, from necessity, be in the case of the inland stream when the occupancy and volume of the latter are compared with those of the river. The flow of the river amounts to about ten thousand cubic feet per second, while that of the stream is not over seventy feet per second, so that the occupancy of three or

our families upon the latter would afford greater danger of pollution than all the occupancy upon the river above our intake, when calculated as to their relative proportion in value and numbers.''

This point is not well taken, unless it be admitted that the three or four families on the stream chance to have their privies and drains empty directly into the brook without soil intervention, an arrangement which would, of course, be prevented by the city authorities. The sewerage system of a town turns its contents directly into the river in a raw state and without any purification, such as obtains from intermittent soil-filtration. The river in question is a large one, but it is possible to seriously pollute it, and it would appear that the up-stream towns are making arrangements to do so by the establishment of sewerage systems.

CHAPTER VII.

STORED WATER.

NATURE provides enormous quantities of water stored up in lakes and ponds ready for human consumption, and man frequently supplements this by impounding surface- and deep-seated waters in artificial basins when the natural reservoirs of the district are unavailable or are insufficient in size. Some sharp lines of difference must be drawn between the waters classed under this general head.

Lakes of such great size as to be properly considered inland seas—the Great Lakes of North America, for instance—furnish water of quite constant composition, free from the considerable vegetable contamination so frequently met with in small lakes and ponds. Large as these Great Lakes are, the influence of

	Lake Superior, near Duluth, 40 miles out from shore. March, 1896.	Lake Michigan, at 4-mile crib, Chicago. February, 1897.	Lake Erie, near Erie, Pa., 14 miles out from shore. October, 1897.
Free ammonia	.03	trace	.045
Albuminoid ammonia	.02	.06	.112
Chlorine	2.	5.	3.5
Nitrogen as nitrates	0.0	....	.08
Nitrogen as nitrites	0.0	....	trace
Required oxygen	1.15	1.8	1.25
Total solids	54.	....	134.

the sewage from cities upon their shores is nevertheless beginning to be seriously felt. The pollution of Lake Michigan by the sewage of Chicago is a widely known fact, and the intakes, situated as they are miles from shore, are frequently reached

by the ever-swelling volume of the city's refuse.* Another instance of the same kind is met with at Erie, Pa. That city takes its water from Lake Erie through an intake situated near the shore in a bay formed by a somewhat long peninsula. City sewage is felt at the intake, as is shown by a comparison of the water at that point with a sample taken from the open lake beyond the peninsula.

Cleveland, O., also takes water from Lake Erie, and the writer is informed that an oily taste is occasionally noticed, which can be accounted for only on the supposition that city sewage, containing refuse from the Standard Oil Works, finds its way as far as the intake.

Much opportunity is given in large lakes for sedimentation to come into full play, and settlement is, in consequence, a very great item in the process of the natural purification of their waters.

So far as the American "Great Lakes" are concerned, there is great difference in this respect between Lake Erie and the other members of the group. Lake Erie is comparatively shallow and is stirred to its bottom by every gale. Therefore sedimentation advantages are at a minimum therein.

Examinations of Lake Ontario water by the Toronto Water Board at points 2½ to 3 miles from shore, where the depths ranged from 75 to 182 feet, gave an average of 101 bacteria per c.c. During violent winter storms, with high seas, the number of bacteria per c.c. was very greatly increased.

Dunant found 150,000 germs per c.c. in water from Lake Geneva taken near the shore, and only 38 per c.c. in a sample from the middle of the lake. Percy Frankland examined the waters of two inlets of Loch Lintrathen and found them to contain 1700 and 780 germs per c.c. respectively, while the outlet of the loch contained but 30 per c.c.

Saratoga Lake, which indirectly receives the sewage of

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* See page 39.

Saratoga, is not by any means of large dimensions, yet Currier finds the following evidence of sedimentation:

Surface.................	56 germs per c.c.
13 feet below surface......	54 " " "
32 " " "	163 " " "

In smaller lakes and ponds the influence of surrounding vegetation begins to be felt, often so seriously as to interfere with the use of their waters for potable purposes. For instance, sundry small lakes (averaging 160 acres in water-surface) have been found by the author to furnish waters of the following compositions in parts per million:

	Free Ammonia.	Albuminoid Ammonia.	Chlorine.	N as Nitrates.	N as Nitrites.	Total Residue.
a..............	.005	.420	2	0	0	52
b..............	.025	.800	3	0	.001	84
c..............	.066	.170	3	....	....	46

One of the above waters is from a shallow, lily-grown lake, and is liable to produce temporary diarrhœa in most people. Another comes from a lake so overcharged with vegetable organisms that when the water is "in blow" handfuls of small plants may be gathered from any portion of its surface.

Some interesting observations have been made, chiefly by Dr. Brown, showing the influence of depth upon the character of water in small lakes and storage-reservoirs.

He found that during the summer season, owing to the comparative lightness of the warmer water, no circulation takes place below a depth of twenty feet, that being the usual distance to which wind and wave agitation extends. Fitz-Gerald found that Lake Cochituate, which has an area of 785 acres, is not affected by wind and wave action below twelve feet from the surface. Should a lake be protected from the wind, the aerated layer may extend temporarily only ten feet from the surface, and below this level the cold, stagnant water rests, until such time as the chilling of the upper layer increases

its gravity to and beyond that of the lower layer upon which it floats. When this point is reached, readjustment of relative position is immediately instituted, in accordance with the change in specific gravity, and the water of the lake "turns over."

The formation of this stagnant layer begins in April in this latitude, and circulation is partly re-established in October and completely so in November. With the advent of freezing weather a second period of stratification is inaugurated which continues until the surface thaws again in the spring. Vertical circulation then progresses until the warm sun of later April renders the surface-water so light as to float upon the colder layers beneath, when summer stagnation again begins.

Whenever the lower stagnant layer is brought in contact with decomposing organic matter, as is the case in reservoirs with bottoms from which the vegetation has not been removed, the dissolved oxygen present is quickly used up; quantities of extractive matters pass into solution and the water becomes foul in odor and dark in color.

The following analyses, published by the Massachusetts State Board of Health, show this diminution and ultimate total exhaustion of dissolved oxygen in the stagnant layer. The amount of oxygen present is expressed as percentages of the amount required to saturate the water at the temperature when collected.

DISSOLVED OXYGEN AT DIFFERENT DEPTHS.

JAMAICA POND, BOSTON, JULY 14, 1891.

Depth.	Temperature of Water, Deg. Fahr.	Per Cent of Oxygen.
Surface	75.4	100
10 ft. below surface	75	100
20 ft. " "	54	49
30 ft. " "	42.4	29.47
35 ft. " "	42	4.18
40 ft. " "	42	0
47 ft. " "	41.3	0

LAKE COCHITUATE, BOSTON WATER-WORKS (AUG. 17, 1891).

Surface	74.7	79.15
10 ft. below surface	66.4	83.69
20 ft. " "	53.6	35.86
30 ft. " "	49.3	21.33
40 ft. " "	48.2	20.93
45 ft. " "	48.2	1.65
50 ft. " "	45.7	0
57 ft. " " (bottom)	44.8	0

Even though the bottom of a lake or reservoir be perfectly clean and sandy, the dissolved oxygen must surely diminish in the lower layers of water, for no water is without some oxidizable contents, but it will not be reduced to zero, nor will the water become damaged in quality.

Uniform experience goes to prove that good water may be preserved in properly constructed reservoirs without deterioration for indefinite lengths of time. It must be remembered, however, in this connection, that to keep a ground-water in good condition it is necessary to cover the reservoir. Such waters are usually charged with mineral matter suitable for plant-food, and the higher organisms will be very likely to grow therein unless light be excluded. Thus the great reservoirs supplying the spring-waters of Paris are kept entirely dark, with the best of results. Reservoirs used to store filtered surface-waters should be likewise dark, for the same reason.

Algæ depend for their development upon material furnishing nitrogen. Water containing a moderate amount of this element washed from natural sources will maintain but a small growth of such plant-life, but where nitrogen is present in great quantity as nitrates, as is often the case in deep-seated waters, the development of algæ is often excessive during reservoir storage.*

* In this connection see an excellent article by Rafter on "Fresh-water Algæ and their Relation to Purity of Public Water-supplies," Am. Soc. C. E., xxi. 483.

Experience in Massachusetts, as elsewhere, indicates that storage of surface-waters in open reservoirs causes but little change in the character of such waters, and that what small change does take place is beneficial. The bad effect of the storage of ground-waters in such reservoirs is, however, quite strongly marked. No better illustration could be given of the different actions of surface- and ground-waters during similar storage in open reservoirs than to call attention to the conditions existing at Atlantic City, N. J. The two supplies of the city, although afterwards mixed, are stored separately in basins of about the same size and separated one from the other by only a narrow embankment a few feet wide. See illustration on page 279. The water shown in the foreground is from flowing wells which deliver through the bottom of the reservoir. It is continually filled with large masses of green growth. The reservoir seen in the background holds surface-water, admitted by canal, and is entirely free from growths of any kind. A more instructive instance of varied action under identical storage conditions could hardly be expected.

To put it tersely, it may be said that a water from a dark source should be stored in the dark and *vice versa;* filtered water being the exception, as above noted, and requiring dark storage irrespective of its source.

Commenting upon the following table, F. P. Stearns says: "In interpreting these analyses it will not be far out of the

CHANGES IN GROUND-WATER DURING OPEN STORAGE.

Parts per Million.

	Albuminoid Ammonia.		Nitrogen as Nitrates.
	Dissolved.	Suspended.	
Water entered reservoir May 22...	.016	.000	.600
May 24...	.054	.170	.450
May 29...	.082	.406	.040
June 26...	.128	.060	.030

way if we consider the nitrates as representing food; the suspended albuminoid ammonia, the algæ and other organisms; and the dissolved albuminoid ammonia, an extract of dead organisms, with, perhaps, in addition, the excreta of live ones."

That the stagnation of water in the lower levels of a reservoir is not in itself objectionable has been shown by Dr. Drown in his study of reservoirs Nos. 3 and 4 of the Boston Waterworks:

"Water in the stagnant layer does not become foul unless there is decomposable organic matter present. Thus in Basin 4 of the Boston Water-works, which was carefully prepared for the reception of the water by the removal of all soil and vegetable matter, and is supplied with a brown, swampy water from a watershed almost entirely free from population, the water is good at a depth of 40 feet, because the water contains very little organic matter with a tendency to decomposition.

RESERVOIR NO. 3, BOSTON WATER-WORKS (AUG. 20, 1891).

	Temperature, Deg. Fahr.	Per Cent of Dissolved Oxygen.
Surface	74.7	85.88
6 ft. below surface	74.7	85.06
12 ft. " "	70.9	58.97
14 ft. " "	——	0
15 ft. " "	——	0
17 ft. " "	——	0
19 ft. " "	——	0
21 ft. " " (bottom)	62.8	0

RESERVOIR NO. 4, BOSTON WATER-WORKS (AUG. 20, 1891).

	Temperature, Deg. Fahr.	Per Cent of Dissolved Oxygen.
Surface	74.7	84.50
10 ft. below surface	70.9	84.42
20 ft. " "	61.9	28.02
30 ft. " "	70	27.42
35 ft. " "	54.7	16.28
36½ ft. " " (bottom)	54.7	15.10

VIEW OF WELL-BASIN, IN THE FOREGROUND, AND CANAL-BASIN, IN THE BACK GROUND, AT ABSECON PUMPING-STATION, ATLANTIC CITY, N. J.

"The contrast in the condition of the water in these two reservoirs is very striking. Reservoir No. 3, in which the oxygen is exhausted at a depth of 14 feet, receives a not inconsiderable amount of direct pollution from the towns of Marlborough and Southborough, while the drainage-area of Reservoir No. 4, as has been already said, is very sparsely populated."

The following chart, which graphically shows the temperature variations during the summer season for different depths of Lake Cochituate, was prepared by Desmond FitzGerald for the report of the Boston Water-works. It will be noted that the temperature curves run together at the times of the semi-annual "turn-over."

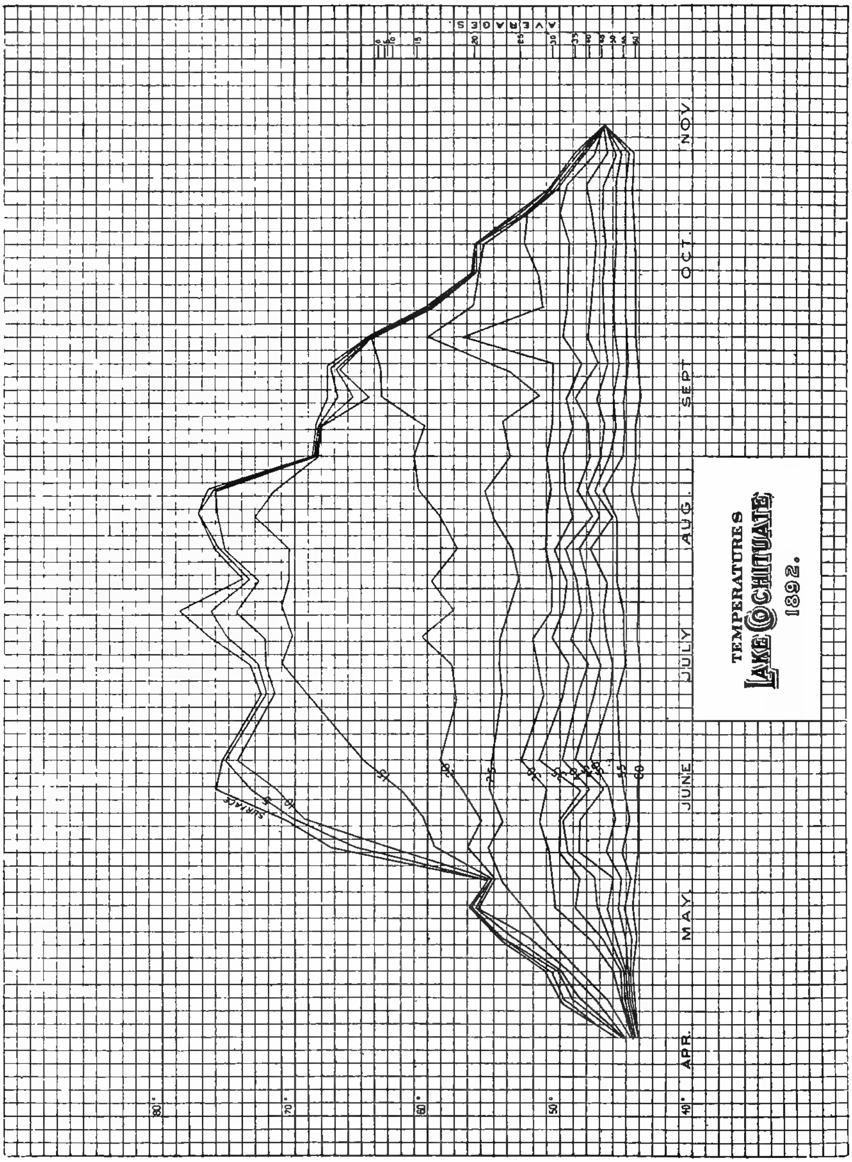
As supplementary to his investigation concerning the amount of dissolved oxygen in the water of ponds and reservoirs at different depths during the summer months, Dr. Drown made similar determinations during severe winter weather, when the waters in question were covered with thick coatings of ice. The winter results fully confirmed those of summer, and showed that with exclusion of air the dissolved oxygen diminished in proportion to the quantity of organic material present, "reinforcing the argument for the storing of clean water in clean reservoirs." *

As a result of the "turning over" in the spring and autumn the waters of lakes and deep reservoirs possessing dirty bottoms become fouled to a greater or less degree throughout their entire masses by virtue of the mingling of the waters of all layers during these periods of vertical circulation.

The deeply stained water of the bottom imparts a shade of its color to the body of the water at large, and the nitrogenous matter in solution, quickly oxidizing to "nitrates," furnishes food for countless millions of "diatoms," whose growth,

* Rep. Mass. Board of Health, 1892, p. 331.

A case of trouble from insufficiency of dissolved oxygen in the water of the Schuylkill River has already been referred to, p. 208.


TEMPERATURES
LAKE COCHITUATE,
1892.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
40°
50°
60°
70°
80°
SURFACE
AVERAGES.

development, and decay cause many of the unpleasant tastes and odors with which our city supplies are so frequently afflicted.

The Boston Water-supply Department has made extended study of the coloring-matter so common to the stagnant layer, and of the observed facts that the color at first deepens on exposure to air and afterwards bleaches out. The department finds that these phenomena are more strongly marked in proportion as the bottom-water is rich in salts of iron and manganese.

Those familiar with the properties and behavior of ferrous and ferric salts would have predicted that the soluble and light-colored ferrous compounds would, upon exposure to the atmospheric oxygen, oxidize to darker ferric salts, and ultimately fall as insoluble hydrated oxide, leaving the water bleached.

Sundry vegetable and peaty extracts are exceedingly difficult to decolorize, and waters containing them cannot be rendered colorless by storage in presence of light and air in a period short of many months. Improvement in color always results from storage, but its entire removal is often impossible.

FitzGerald reports the following seasonal changes in color of the waters of the Sudbury: The highest color is attained in the month of June, and then it rapidly lessens until September. Towards the end of October the color increases again until December, and then decreases until it reaches its yearly minimum in the middle of March. He offers the following explanation: In the early spring the swamps are overflowed and the color is low on account of dilution. Concentration causes increase in color until early summer, after which time the swamp pools cease to overflow, and consequently the brooks grow clearer. Autumn rains wash highly stained water into the streams, increasing their color, which is afterwards lessened in winter by the freezing up of the swamp sources.*

* "Metro. Water-supply," Rep. Mass. Board of Health, 1895, Appendix 3.

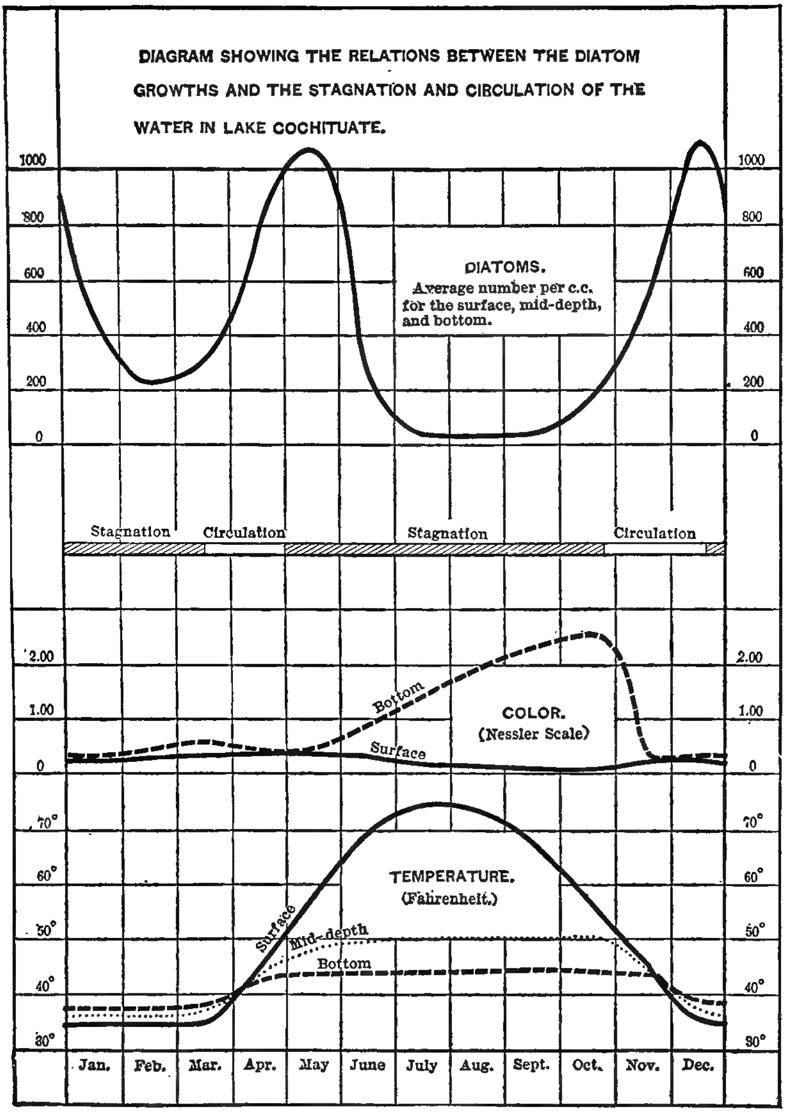
Much more recently FitzGerald has experimented regarding the action of lights of different colors on the reduction of the brown color of water. The water under experiment was exposed during one month of summer in bottles of colored glass.

	Original Color.	Final Color.	Per Cent Reduction in Color.
In white bottle	1.05	0.39	
" " "	0.85	0.19	
Mean	0.95	0.29	69.48
In blue bottle	1.02	0.39	
" " "	0.85	0.24	
Mean	0.93	0.31	66.66
In yellow bottle	1.02	0.58	
" " "	0.85	0.46	
Mean	0.93	0 52	44.09
In red bottle	1.02	0.54	
" " "	0.85	0.47	
Mean	0.93	0.50	46.24

To return for a moment to what has been said concerning the growth of diatoms, the chart on the page opposite, prepared by G. C. Whipple,* makes the relation of such growth to the periods of vertical circulation very distinct.

Among other conclusions Mr. Whipple found that diatoms flourish best in ponds having muddy bottoms; that their growth is directly connected with the phenomenon of stagnation; that their development does not occur when the lower strata of water are quiescent, but rather during those periods when the water is in circulation from top to bottom; that the two most

* "Observations on the Growth of Diatoms in Surface-waters."



(AFTER WHIPPLE.)

important conditions for their growth are a sufficient supply of nitrates and a free circulation of air; and that both these conditions are found during the periods of vertical circulation.

Light also stimulates their growth. Hence it was to have been expected that a darkly stained water, which does not easily admit light, would prove a less favorable medium for the propagation of diatoms than a water of colorless character.

As has been said, air is essential to the abundant growth of these minute organisms, but the introduction of such air by means productive of violent agitation of the water would seem to be quite fatal to their development; probably through direct damage to the fragile cells of the plants.

Whipple observed the bad effect upon the growth produced by blowing a current of air through the water.* As a deduction from this we note a benefit to be derived from reservoir fountains and other means of agitation.

It has also been shown † that many organisms of fragile structure are broken up by the pressure and currents of the mains, and that others die therein from lack of light and food. The badly smelling oil is thus liberated by disintegration, and as a result the water of the mains, as drawn at the taps, may smell worse than that of the reservoir.

Again, it must be noted that the same organism may produce two very different odors, one during its period of development and quite another one at the time of its decay. For instance, an abundant growth of *anabæna* causes a most distinct smell of "green corn" while the plants are yet alive, which changes to a pronounced "pig-pen" odor during the process of their decomposition. This change is quite characteristic.

While speaking of *anabæna* let it be added that the author observed a very interesting growth of this diatom in the reservoir of a Western city.

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* *J. N. E. Water-works Asso.*, xi. 3.

† *Ibid.*, xii. 7.

The plant was distributed throughout the water from the surface to a depth of ten feet, producing disagreeable taste and smell in that part of the water, but leaving the deeper portions unaffected and entirely fit for use. It is worthy of record that a similar growth of the plant occurred in the same reservoir the year previous and that, because of a sudden change of temperature, the water of the reservoir "turned over" in a single night, thereby distributing the organism and admitting highly objectionable water to the mains. Widespread public complaint was, of course, the immediate result.

This instance but adds weight to the demand for such form of gate-house in all city reservoirs as will permit of tapping off the water at any desired level; and it also shows, not only the necessity for biological and temperature observations, but that the entire storage need not be wasted because of the lack of fitness of a portion of the supply.

One of the most instructive cases of reservoir contamination by aquatic growth occurred at Brooklyn, N. Y., in 1896, and is reported by Leeds and Whipple in *Engineering News*, July 1, 1897. The cause of the difficulty was an abundant development of *asterionella*.

From analysis of the bodies of asterionella, Whipple and Jackson found that in order to support a growth of such diatoms the water must contain the following, in parts per million:

N as NO_3	.079
SiO_2	1.780
Fe_2O_3	.083
CaO	.052
MgO	.045
K_2O	.043
Mn_2O_3	.030
SO_3	.014
Total solids	3.600

They consider the silica, iron, and manganese as those items most likely to be lacking in quantity sufficient to support an abundant growth of the plant.*

As is well known, the city of Brooklyn uses a mixed water, part of it being derived from wells driven into the sandy soil of Long Island and the balance of it being from surface sources, such as Jamaica pond. The surface-water supplied the seed, the ground-water the necessary food, and the open Ridgewood reservoir, where the mixed waters were stored, allowed the light and heat of the summer sun to encourage abundant growth. The remedy in this case lay in using a by-pass around the reservoir and direct to the mains, until such time as the reservoir water had recovered its normal quality. Light is essential to such a growth and the use of a by-pass was cheaper than constructing a reservoir cover.

ORGANISMS AND THE NUMBER OF THEM PER C.C. REQUIRED TO PRODUCE ODOR OR TASTE.

Reported by Whipple.†

	Number required per c.c.	Character of Odor and Taste.
Synedra pulchella	5000	earthy—vegetable
Cyclotella	5000	aromatic—fishy
Melosira	over 3000	earthy—vegetable
Anabæna	1700 standard unity	mouldy grass
Scenedesmus	25000 " "	vegetable—aromatic

As to asterionella Whipple finds, by experiment, the following relations between the aromatic, fishy odor of the water and numbers of the organism present per c.c.: ‡

Odor.	Number per c c.
None	0 to 1,000
Very faint	500 to 3,000
Faint	1,000 to 5,000
Distinct	3,000 to 15,000
Decided	10,000 and over

* *J. N. E. Water-works Asso.*, xiv. 19.

† See also *Engineering News*, June 7, 1900.

‡ *J. N. E. Water-works Asso.*, xiv. 1.

NUMBERS OF ORGANISMS FOUND BY WHIPPLE IN INSTANCES OF OBSERVED ODOR.

Organism.	Odor.	Date.	Locality.	Number of St. Units per c.c.
Asterionella..........	Aromatic, geranium, fishy	Dec., 1897	Mt. Prospect Res., Brooklyn	50,000
Cyclotella............	Faint aromatic	April, 1899	Ridgewood Res., Brooklyn	25,000
Diatoma.............	" "	Oct., 1900	Mt. Prospect Res., Brooklyn	13,000
Meridion	Aromatic	May, 1894	Pond at Chestnut Hill, Mass.	5,000
Tabellaria............	"	May, 1890	Lake Cochituate	2,500
Melosira.............	Vegetable	Oct., 1900	Hempstead, L. I.	8,000
Synedra.............	"	Sept., 1897	Ridgewood Res., Brooklyn	20,000
Volvox..............	Fishy	....	Rochester, N. Y.	....
Eudorina.............	Faintly fishy	Aug., 1900	Mt. Prospect Res., Brooklyn	900
Pandorina............	" "	Aug., 1895	Pond at Chestnut Hill, Mass.	5,000
Dictyosphærium.......	" "	Aug., 1897	Mt. Prospect Res., Brooklyn	1,000
Anabæna.............	Grassy and mouldy, green corn, etc.	Aug., 1899	Long Pond, N. J.	9,000
Rivularia............	Grassy and mouldy			3,000
Aphanizomenon	Grassy	Oct., 1896	Laurel Lake, Fitzwilliam, N. H.	3,000
Uroglena.............	Fishy and oily	April, 1892	Norwood, Mass.	17,000
Synura...............	Cucumber	Oct., 1891	Glen Lewis Pond, Lynn, Mass.	7,000
Dinobryon............	Fishy and rockweed	July, 1890	Scott Res., Fitchburg, Mass.	4,500
Bursaria	Fishy, Irish moss			
Peridinium	Fishy, clam-shells	July, 1891	Mystic Lake, Somerville	7,500
Glenodinium..........	Fishy	Aug., 1893	" " "	10,000
Chlamydomonas......	Fishy and mouldy	Nov., 1898	Spot Pond, Malden, Mass.	700
Cryptomonas.........	Aromatic	Jan., 1900	Creek, Lodi, N. J.	10,000
Mallomonas	" , fishy	Sept., 1896	Lake Cochituate	3,500

In a letter to the author Mr. Whipple gave the table on page 289 showing numbers of organisms found in cases of observed odor.

He adds: "As to stating the number necessary to cause a noticeable odor, I do not feel sure enough about the figures to quote any. It might be done approximately in a few cases, as with asterionella, but I am sure that we cannot do more than guess at most of them."

An aquatic plant known as *crenothrix* gives much trouble at times because of its tendency to develop in the street-mains and clog the pipes. Iron is requisite for its growth, however, and no such difficulty is to be feared in waters which are but slightly ferruginous. It is often discovered in mains quite unexpectedly, being washed therefrom by the current attending hydrant flushing, or by the draft caused by fire-engines; and its long, rusty filaments have been sometimes taken for horse-manure, with consequent depreciated opinion of the character of the water-supply. Removal of the iron by oxidation and filtration is the best guard against the occurrence of this growth.

P. Frankland finds as a result of his observations that green aquatic vegetation is hostile to bacterial life.

Reinsch records similar observations. He found five times as many bacteria in the water above the sand in those of the Altona filters where green algæ had not grown than were present in the filters where the amount of vegetable growth was excessive.

These views are endorsed by observers in this country.

In view of what has been said the bottom of a proposed reservoir should, so far as possible, be cleaned of all vegetable material, and it is even desirable also to remove a portion of the upper soil, as it commonly carries quantities of organic remains. Decomposition of recently killed vegetation takes

place under water quite rapidly at first, but the process is shortly converted into one of exceeding slowness, particularly where the covering water is deep. So permanent, in fact, is timber which has been deeply submerged that the oaken piles which in prehistoric times supported the buildings of the Swiss "lake-dwellers" are still firm and solid, although black in color. On the other hand, alternate flooding and exposure to sun and air is quickly destructive of vegetable matter, and as a result a reservoir with very gently sloping sides furnishes conditions favorable to a contaminated water-supply, particularly if it be liable at times to considerable reduction in depth of water. Even though the level of its contents be always maintained at high-water mark, sloping sides would permit thin layers of water to be overheated by the summer sun, thus encouraging abundant growth of aquatic plants, which subsequently decay, to the damage of the water.

It is especially undesirable to permit the bottom of a storage-reservoir to remain exposed for more than one season, for the reason that vegetation will develop in such quantity as greatly to injure the water when the bare slopes are again submerged.

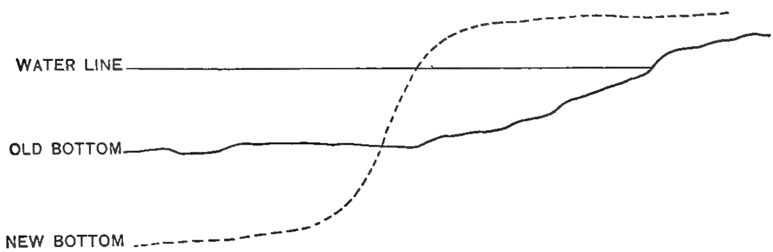
Owing to experience already obtained in such matters the Boston authorities are removing the soil from the site of the new Nashua reservoir (about seven square miles of area) at a cost of $2,909,000. Some 800 holes were dug to determine the average depth of this layer, and it was concluded to take away 9 inches from the wooded portions and 11½ inches from the cleared lands.*

As a provisional standard, 1½ to 2 per cent of organic matter, as determined by the loss on ignition of the sample dried at 100° C. (212° F.), was fixed upon as the permissible limit of organic matter that might be allowed to remain on the bottom and sides of the reservoir.

* Rep. Mass. Board of Health, 1895.

No stripping of the soil from the bottom of the great Vyrnwy reservoir, supplying Liverpool, was done, but the water is filtered before delivery for consumption. Filtration is so common in Europe that the same care in storage is not so necessary as it is in this country, where the practice is to pipe the raw water direct to the consumer.

Depth of reservoirs is not so important as the presence of food-supply in the matter of the existence or absence of organisms. The Massachusetts Board of Health reports the case of Pilling's Pond, a very old storage-reservoir, eighty-five acres in surface, with an average depth of only three feet. No abnormal growths appeared in this reservoir, nor did the water become offensive, although its temperature at times reached 80° F. The explanation offered is that, owing to the age of the reservoir, the bottom mud no longer contains food-supply.* This negative result could not be expected in a new unstripped reservoir of like dimensions, and in order to guard against undesirable aquatic growths both the stripping and the deepening of such a basin could be best accomplished by one and the same operation, according to the method so strongly recommended by FitzGerald and sketched herewith.



It is particularly desirable that no depressions should be permitted to remain upon a reservoir bottom, which could become cut off from the receding water as the basin was drawn down, and thereby become stagnant pools. Such spots would

* Rep. Mass. Board of Health, 1890 [1], p. 749.

surely become breeding-places for algæ growth. Free drainage should be provided for all pockets of this kind, or, better still, they should be filled up. It may be said here that the work of stripping a reservoir bottom is sometimes complicated by the occurrence of deposits of soft material rich in organic products and too deep to be economically removed. It is good practice to fill in the surface of such places with good sand or gravel, after having taken away the more superficial portion.

Sulphuretted hydrogen frequently adds its disagreeable smell to the offensive odors occurring in new reservoirs, particularly shallow ones. The decomposition of vegetable material, killed by flooding, causes a reduction of the sulphates present to sulphides, and these sulphides are further acted upon by the acids also formed by such decomposition, with liberation of the foul-smelling gas. The author found this gas on one occasion due to a somewhat unusual cause. The reservoir-dam had been built of blast-furnace cinder, and the water was, in consequence, strongly impregnated from the sulphur compounds contained therein.

Waters from underground sources should be distributed for use as soon as possible after they have been brought to the surface; for, as we have seen, they are commonly well supplied with plant-food in solution, and, under the influence of light and air, there is danger of abundant development of objectionable algæ if much time for open storage be allowed.

With surface-waters the case is quite the reverse, and long storage becomes a distinct advantage if the reservoir be clean.

Sedimentation of suspended impurities, and destruction of bacteria by simple lapse of time, are two sources of benefit arising from the impounding of surface-water.

Bacteria often die but slowly, and although a large percentage of their number will disappear through storage, it

should not be forgotten that they are very small and very light, and consequently are very long in settling; so that it should not be expected that a reservoir could do the efficient work accomplished by a filter.

The following table, showing the influence of sedimentation as measured by the number of bacteria per cubic centimetre of water, is taken from the report of the Cincinnati Engineer Commission:

Bacteria, per c.c. of water.		Reduction of Bacteria by Sedimentation.
Cincinnati (Raw).	Covington (Settled).	
1472	272	88.32
1599	194	87.87
5062	172	96.60
....	182	96.41
1656	53	96.80
2042	56	97.26
1561	63	95.96
1526	75	95.09
684	20	97.08
329	26	92.10
1232	112	90.91
1144	84	92.66
1436	102	92.90

The water for Cincinnati is taken from the Ohio River and delivered to the consumers with but a few hours' subsidence in the Eden Park reservoir, while the water of Covington is carried for an average of thirty-two days in the subsiding-reservoirs before it is delivered to the consumers.

From these tests the average reduction of bacteria in the Ohio River water by thirty-two days' subsidence amounts during the months of January and February to nearly ninety-four per cent.

Percy Frankland found the following numbers of bacteria per cubic centimetre in Thames water at the intake of the Grand Junction Company, and in water from the large reservoir of the company, where the greater part of it had been stored for six months, and none for less than one month:

Intake	1991 bacteria
Reservoir	368 "

The West Middlesex Company causes its water to pass through two storage-reservoirs before it is delivered upon the filter-beds. The influence of such passage is seen in the following counts of bacteria as made by Frankland:

Intake at Hampton	1437 per cubic centimetre
After passing first reservoir	318 " " "
" " second "	177 " " "

The value of sedimentation was shown at Philadelphia during the prevalence of typhoid fever in that city in 1891. "By much the highest mortality is in the twenty-ninth and thirty-second wards. This is an elevated section of the city, newly improved and occupied for the most part by well-to-do people. The drainage is good and the laws of health are doubtless as well observed as in any other portion of the city. But these wards are too high to draw water from the subsiding reservoir, and they are accordingly furnished by direct pumpage from the river. This is the case also in the twenty-eighth ward adjoining, and the district so supplied extends southward including the fifteenth ward, another well-to-do part of the city where typhoid is especially prevalent. These four wards, furnished by direct pumpage, have a population of 184,000, and report 317 cases of typhoid fever, or at the rate of 172 to 100,000 inhabitants."

Influence of sedimentation * in protecting against typhoid is well shown at New Albany, Indiana, which is opposite Louisville, Ky. Practically the same water is furnished the two cities, except that the New Albany supply is somewhat more impure, being contaminated in part by Louisville sewage. New Albany possesses three reservoirs, delivering one into the

* See also "Bacterial Reduction by Storage," *Engineering Record*, Aug. 13, 1898; "Influence of Dredging Lake Bottom, Public Water-supply," Hill, p. 96.

other, through which the entire supply flows, taking about one month in the passage. Louisville uses her water after only a short storage. New Albany has a typhoid death-rate of less than 30 per 100,000. The corresponding rate for Louisville is about 75.*

The influence of precipitating mud in hastening the fall of bacteria was investigated by Krüger.† By the use of one half gramme of fine sterilized potter's clay per litre of water he obtained the following counts of bacteria per cubic centimetre of water. The temperature was maintained at 55° F.

As has been pointed out elsewhere this action was to have been expected, in view of the well-known tendency of falling solids to drag down other matters with them even, at times, when such other bodies are in solution. Bacteria, being in suspension, are more readily influenced by the depositing silt. The very large counts observed in the bottom samples of the water containing clay are doubtless due to the fact that the sterilized clay contained abundant food for the germs and favored their rapid multiplication during the period of observation.

Doubtless the most apparent advantage to be obtained from storage is the removal, by sedimentation, of those suspended materials, mostly of mineral character, which cause unsightly turbidity in water.

The theory of the clearing of water by settlement, and the most economic size for purely sedimentation-reservoirs, are questions which have been exhaustively discussed in our engineering societies by such men as J. A. Seddon, Whitney, and others, and reference must be had to their interesting and voluminous papers for full information.

But it may be here said that the bulk of sediment capable

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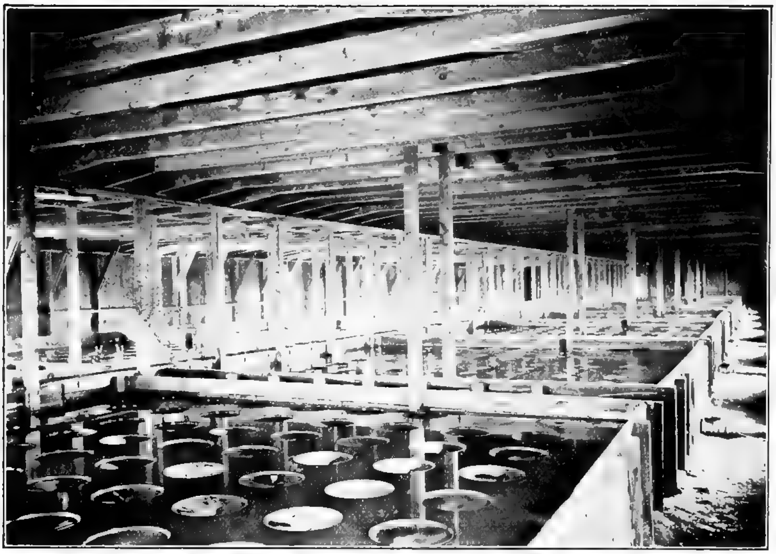
* *J. N. E. Water-works Asso.*, xiii. 15.

† *Zeit. f. Hygiene*, vii. 86.



SETTLING-TANKS SHOWING "SKIMMING" DISKS. DENVER, COLO.

SAME TANKS EMPTY OF WATER SHOWING DEPOSIT OF SEDIMENT.

[*To face page* 297]

of falling within a reasonable length of time will be found to deposit within about twenty-four hours, the balance settling out with much slowness. It is therefore very questionable economy to provide for a sedimentation period of over thirty-six hours.

Whitney calls attention to the fact that "as the material in suspension grows finer the weight of each particle decreases so much more rapidly in proportion than its surface that there is, relatively, a larger amount of surface area in these fine particles, and a great deal of surface friction in their movement through a medium. Consequently they settle very slowly."

"Ordinary convection currents, induced by normal changes of temperature, would be sufficient to keep these fine particles in suspension, as it is known that currents of air keep fine particles of dust and ashes in suspension." *

	Water with Clay.			Control Water Containing No Clay.		
	Top.	Middle.	Bottom.	Top.	Middle.	Bottom.
After standing 2 hours	575	887	33,495	5340	6110	5480
" " 20 "	521	155	43,595	5960	6710	6210
" " 50 "	6933	6190	66,350	7230	5987	6924

Note that the high degree of removal does not follow high sediment present, but that the relation is irregular.

One of the most peculiar forms of settling-chamber the author has seen is in use by the Denver Union Water Company, at Denver, Colorado. It is readily understood by reference to the illustrations on opposite page. The tanks are each 20 × 20 × 3½ feet, and water is admitted through nine rectangular orifices near the bottom. The effluent is "skimmed" from the surface by ninety 16-inch disks which connect with the underdrains by means of one-inch vertical iron pipes. The

* Wiley's "Agric. Anal.," i. 180.

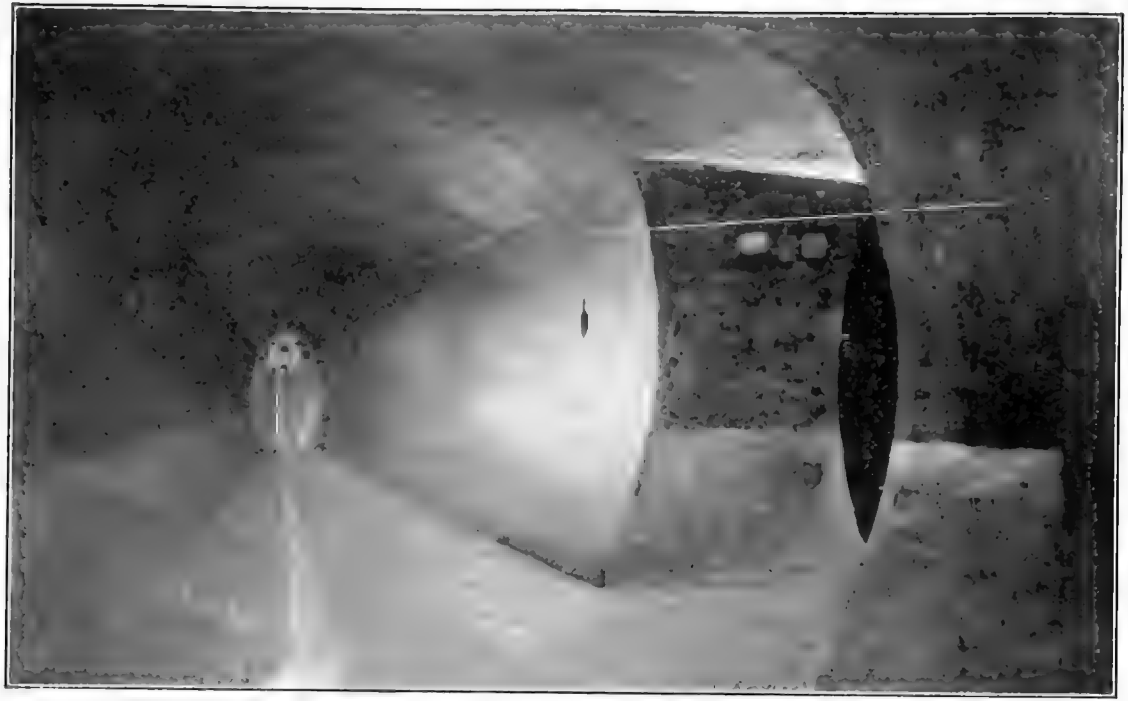
EXPERIMENTS ON THE PRECIPITATION OF THE SUSPENDED MATTER IN OHIO RIVER WATER, AT CINCINNATI, OHIO.

From Report of the Engineer Commission.

Date, 1889.	Hours of Settling.	Silt held in Suspension, Parts by Weight per 1,000.		Percentage of Silt removed by Settling.
		Before Settling.	After Settling.	
January 7	42.2	0.3635	0.1225	66.3
9	47.0	0.3610	0.1135	68.5
11	46.3	0.2350	0.1435	38.9
13	48.0	0.1005	0.0490	51.2
15	47.1	0 0920	0.0330	64.1
17	47.3	0.3900	0.1305	66.5
21	48.2	0.2011	0.0932	53.6
23	41.5	0.0865	0.0246	71.5
26	40.4	0.0955	0.0220	75.9
29	5.3	0.1640	0.0720	56.1
29	40.3	0.2235	0.0580	74.0
31	30.3	0.2225	0.1098	50.6
February 1	41.2	0.3095	0.0720	76.8
3	31.5	0.2760	0.0910	67.0
4	42.0	0.1900	0 0445	76.5
6	28.2	0.1615	0.0615	61.9
7	40.3	0.1548	0.0560	63.8
9	30.3	0.0555	0 0325	39.6
10	40.4	0.0450	0.0220	51.1
12	30.6	0.0415	0.0360	13.2
13	41.1	0.0462	0.0188	59.3
15	30.2	0.0665	0.0125	81.2
16	39.4	0.2635	0.0330	85.8
18	31.0	0.5425	0.1287	76.3
19	40.5	0.5900	0.1085	81.6
21	31.5	0.5623	0.1628	71.1
22	41.2	0.3780	0.0945	75.0
24	29.6	0.3455	0.0855	75.3
25	40.3	0.3811	0.0930	75.6
27	47.1	0.2940	0.0765	74.0
Average..	38	......	......	64.7

15-inch partitions, shown on the bottom, are arranged to assist in the flushing out of the sediment. At the time of the writer's visit the efficiency of the settling-tanks was represented by a removal of a large part of the suspended matter and of 32 per cent of the bacteria present in the raw water.

Although great storage-reservoirs must of necessity be open, those used for service often demand to be covered,



THE CATACOMBS [illegible]

especially so if the water to be stored be from an underground source. We have already seen that exposure of subterranean waters to sunlight commonly results in development of objectionable vegetable growths. The somewhat peculiar reservoirs at Paris which hold the Vanne spring-water, supplying a large portion of the drinking-water used in the French capital furnished an illustration of dark storage. The springs are about 107 miles distant, and the grade of the conduit-pipes is 1 centimetre per 100 metres (0.4 inch per 328 feet). In order to secure sufficient storage, and yet to economize space within the walls of Paris, two reservoirs were built, one on top of the other.* The lower one is constructed of concrete, and 1800 concrete columns support the upper story, which is of brick. This upper chamber is covered by a roof which rests on brick continuations of the concrete columns. The water area in each reservoir is 272 × 136 metres (892 × 446 feet), and its depth in the upper one is 8¼ feet and in the lower one 13¾ feet. The total storage capacity is 200,000 cubic metres (52,800,000 U. S. gallons). The temperature of the water is constantly 48.2° F. in winter and 51.8° F. in summer. No trouble has ever been experienced with algæ growths or odors. Cleaning takes place but once in five years, at which time about half an inch of compact hard deposit is removed. The reservoirs hold a supply sufficient for about six days.

An underground storage system which will repay a visit is that of Naples, Italy. Old quarries lying in the hill of Capedimonte overlooking the city have been enlarged and cemented with the result shown in the illustration on page 299. Five parallel tunnels have thus been formed some 150 feet below the surface of the ground. Their dimensions are 35.4 feet in height and 30.3 feet greatest width. The depth of water is 26 feet, and the galleries are separated by a space

* The Montmartre reservoirs of Paris consist of three superimposed chamber instead of two.

of rock left unexcavated. The capacity of the five basins is 21,120,000 U. S. gallons.

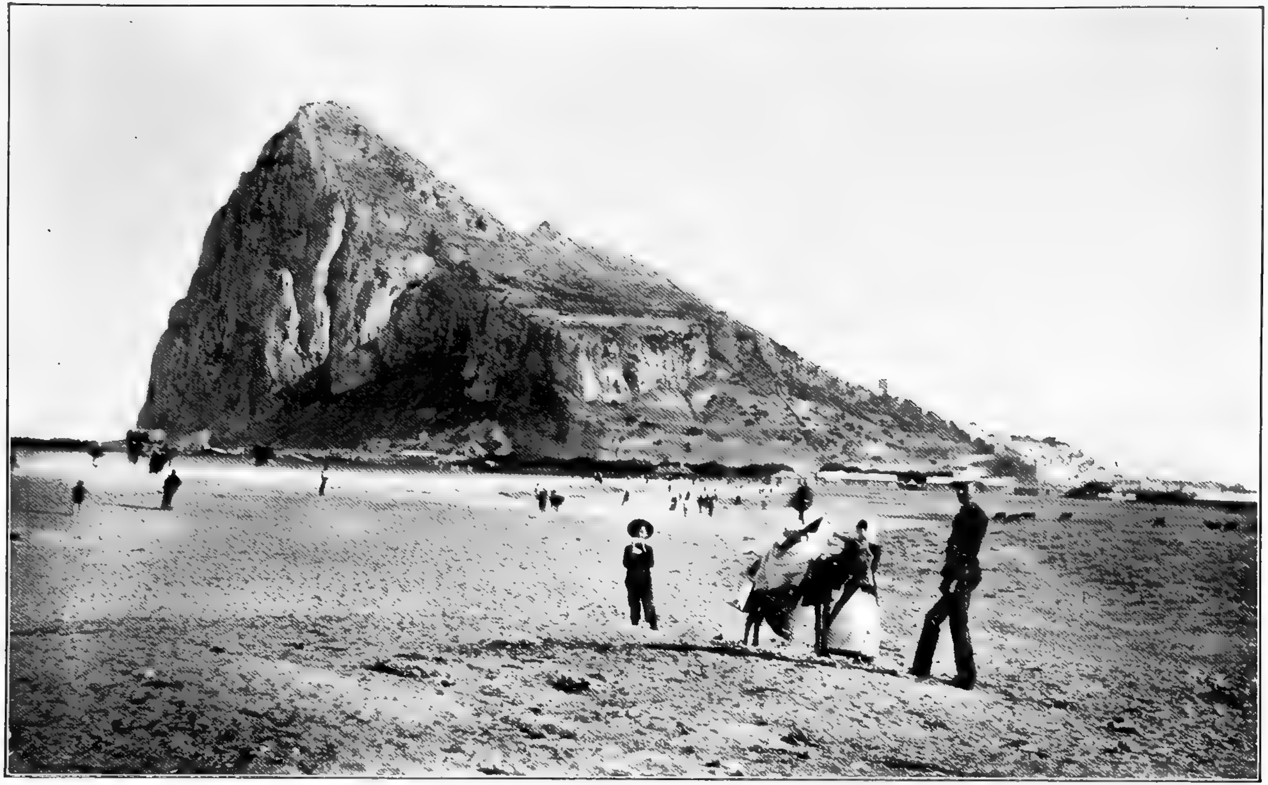
Underground storage of water is also to be found at Gibraltar, and is peculiar in the respect that military precautions are considered in its accomplishment. The writer having had special opportunities for examining this particular system of water-works, a short description of what he saw may not be out of place.

Gibraltar is, beyond all things else, a fortress. The visitor is continually reminded of this fact, not only by the visible signs of military occupation everywhere present, but also by the rules and regulations with which the place positively bristles. The assumption upon which the garrison appears to act is that a state of war continually obtains, and that a hostile attack should be momentarily expected.

So carefully are the military secrets of the rock guarded that even the officers of the post are individually not fully informed as to the nature of the defences outside of the sections where their duties lie. To such an extent is this carried that the engineer officer whose duty it was to design the works for the new water-supply told the writer that he could not go up the west face of the rock until his pass had been signed in England.

It may be easily imagined that the foresight which goes so far as to cause the garrison to be fed on "siege-rations" one day in each week would not permit the possibility of such garrison being deprived of its water-supply through the operation of an enemy.

The area of "Gibraltar" is small, but that portion of it which is within the old walls and which constitutes the "city" is densely populated. Roughly speaking, the civil population at present may be placed at 20,000, while the garrison numbers 6000. These figures would be, of course, liable to some modification in time of actual war.



"NORTH FRONT," GIBRALTAR.

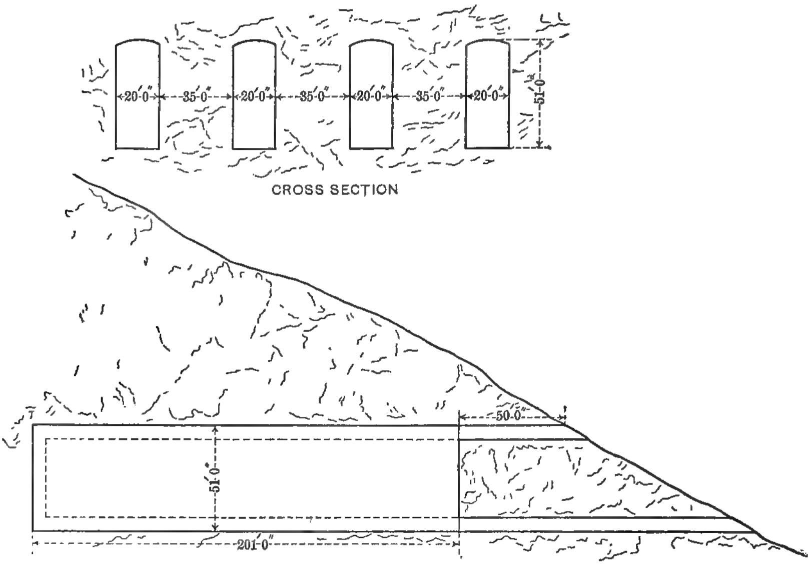
The bold-faced "Rock of Gibraltar," with the pictures of which we are all so familiar, rises sheer from the "Devil's Tower Road," on the "North Front," and faces the land side, not the sea as most people fancy. It looks towards Spain, and makes the approach of an enemy from that direction all the more difficult. The east side is also very precipitous; while the west slope, although decidedly steep, permits of enough fairly level ground being found at its base to furnish a foothold for the "city" with its circumvallating walls.

Gibraltar is not limited to a single source of water-supply. For ordinary uses, such as flushing, street-sprinkling, and the like, a brackish water is used which is derived from wells sunk in the flats north of the rock, and near the neutral grounds. The supply so secured is about 25 per cent sea-water in winter and about three times that amount in summer, owing to the variation in seasonal rainfall. It is pumped to a tank located in the "Moorish Castle," a portion of the ancient defences, and flows thence to the town by gravity. This water is metered and charged for at the rate of ¼ peseta for 100 Imperial gallons, or about 40 cents per 1000 U. S. gallons.

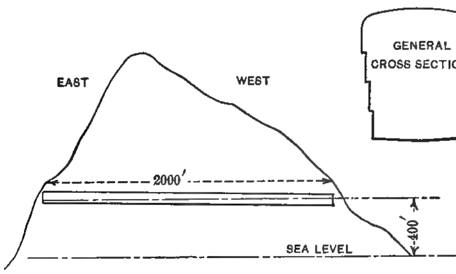
Situated not far from the "Alameda Gardens," on the west slope of the rock, is a distilling-plant for furnishing a potable supply from sea-water. The apparatus is well protected and ready for an emergency, but is not ordinarily in use.

The principal water-supply for Gibraltar is obtained from the rain, and a careful inspection of the west face of the rock will show a whitish patch near the top which acts as the catchment area. This area contains about sixteen acres, and has been carefully cemented at a cost of 1½ pesetas (about 30 cents) per square yard. The water falling thereupon, averaging 33⅓ inches annually, passes through a rough strainer of "polarite" and sand, and is thence delivered into the underground storage-reservoirs, which are at present four in number.

All four storage-reservoirs are of the same size, and are of tunnel form, being 201 feet long, 22 feet wide at the top, and 18 feet wide at the bottom, with a height of 51 feet. The



SECTIONS OF STORAGE-TUNNEL RESERVOIRS AT GIBRALTAR.



SKETCH-SECTIONS OF NEW STORAGE-TUNNEL RESERVOIR AT GIBRALTAR.

sides are stepped off by 4-inch ledges every 7 feet, measured vertically. The sides, bottoms, and ends are concreted and then plastered with four coats of a mixture of equal parts of cement and fine limestone. The filtered rain-water is admitted

WEST FACE OF ROCK, GIBRALTAR (SHOWING CATCHMENT AREA IN UPPER LEFT CORNER).

to each tunnel through an 18-inch cast-iron pipe, carried to the bottom of the chamber.

Security against the shell-fire of an enemy is not the only advantage of this form of water-storage, for it must be remembered that the absolute darkness which prevails under such conditions inhibits the growth of aquatic vegetation, and the temperature of the water is maintained constantly at a low degree, in this instance 50° F.

The exact location of these reservoirs it is not permitted the outsider to know, although their general form and dimensions are given above. The internal measurements are correct, as stated, but the true angle of slope of the exterior rock-face is intentionally withheld. It will be noticed that the exterior ends of the tunnels are not excavated. This is for the protection of the water-supply against the artillery-fire of a besieging force.

Designs have been completed and work is now in hand for a much larger storage system, to consist of a tunnel driven through the entire rock from side to side, excepting, of course, the unexcavated ends. Exact information covering this development it is, naturally, impossible to secure, but the rough sketch given will sufficiently illustrate its general character.

The tunnel will be about 400 feet above sea-level, will be 2000 feet long, with a sectional area of 1311 square feet, and will dip slightly toward the west. It is estimated to cost £150,000, or about $730,000. Necessarily the catchment area will have to be materially increased to provide water enough to fill this new reservoir.

Light, inexpensive covers are often thrown over reservoirs of considerable size and the sun's rays thereby excluded, with the result that algæ growths become arrested. Pasadena, Cal., has such a construction, and so likewise has Quincy, Ill.*

* See *Engineering News*, June 9, 1898, and August 17, 1899.

The general character of the Pasadena cover is easily determined from the illustration on page 311, and the cost was as follows:

259,966 square feet of lumber	$4856
9373 feet of 2-inch pipe for posts (including 551 caps and freight)	987
Hardware	203
Mill-work (labor making corbels)	27
Cement (around foot of posts)	6
Engineering	151
Labor (including superintendence)	1004
Total	$7234

The area covered was 166,000 square feet, at a cost of 4.36 cents per square foot, or $345 per 1,000,000 gallons of storage.

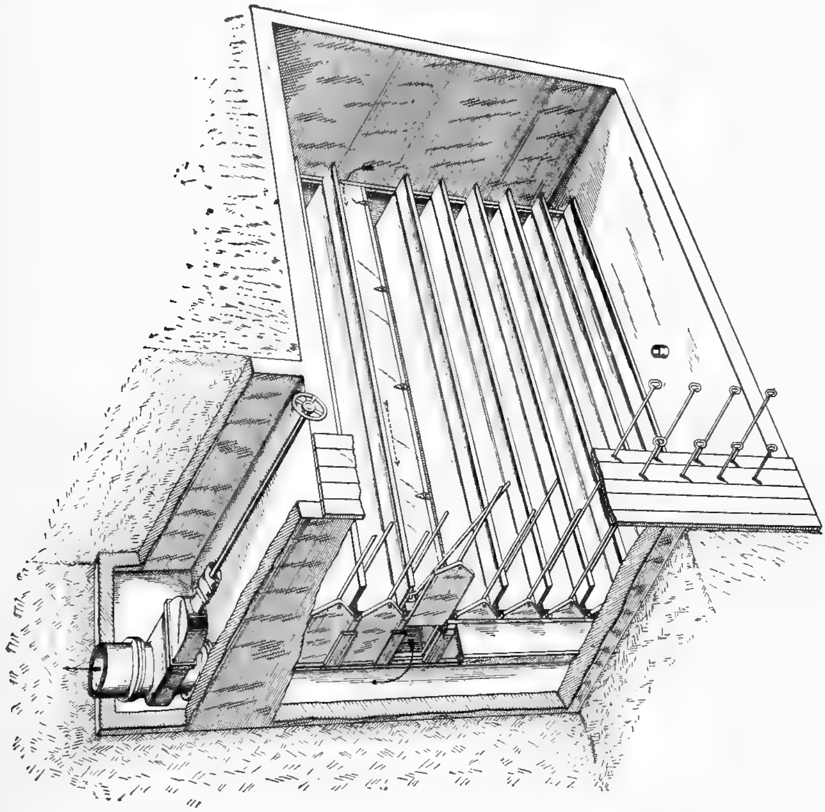
It is important to note that in all such covers the boards should be laid north and south, so as to avoid too long exposure of the same water-surface to what sun rays may enter through the openings between the planks.

With reference to the question of ice formation the method of procedure proposed at Quincy is to "pump continuously into the reservoir during ice-making weather, and when it is full stop the pumps and supply the city from the reservoir until it is necessary to resume pumping. By this plan of either raising the water or allowing it to fall the ice does not become attached to the posts sufficiently to do any damage."

Whatever the design of the settling-basin may be, it is desirable that means be provided for easy removal of sediment. One form, invented by the writer, for quick cleaning is illustrated on page 313. The illustration shows the method of removing deposit from reservoirs without throwing them out of use. It will be seen that a series of partitions, provided with hinged covers, is placed in the bottom of the reservoir. The

COVERED RESERVOIR, PASADENA, CAL.

compartments thus formed are open at one end and closed at the other by lift-gates, which lead into a common header. During sedimentation the covers stand vertical and the silt falls



DEVICE FOR CLEANING A SETTLING-RESERVOIR WITHOUT THROWING IT OUT OF SERVICE.

to the reservoir bottom. Upon closing down the shutters the deposit is trapped beneath them. If one or more of the gates be raised, the head of water forces the sediment out into the "header" and thence into the sewer. For large reservoirs such a device is multiplied, and the shutters and gates are operated from paths of light construction.

For the removal from a large reservoir of a considerable

growth of grass the author saw barbed wire in successful use at Denver, Col. One end of the wire was fastened at a point on shore and the other was hauled by a team of horses over quite a sweep of bottom. The weeds were cut off near the roots or else dragged out bodily and afterwards floated ashore.

The lining of a service-reservoir is an important matter, and, unless properly looked after, may result in serious difficulties.

Phipson reports a case * where a new subterranean reservoir, built to store rain-water, and lined with hydraulic cement of bad quality, permitted its contents to become so charged with calcium hydrate as to be strongly alkaline to litmus paper. The water was thus rendered useless for domestic purposes.

Where possible of application, very excellent results are obtained from the use of a lining of asphaltum.

The Queen Lane reservoir, Philadelphia, is an instance, among many, of successful application of asphalt for the construction of an impervious lining.

"If the same care is exercised in the use of asphalt for reservoir linings as is essential in its use for street pavements, there is no doubt that it is the coming material for making reservoirs impervious." †

Whipple and Jackson have issued a paper ‡ upon the "Action of Water Asphalts," in which they conclude that "by far the most important action which occurs is that produced by oxidation of the asphalt by means of the dissolved oxygen in the water."

Some failures have occurred in the use of asphalt linings which arose from improper mixing of ingredients and, more particularly, from faulty supporting material whereon the asphalt was laid, but present practice has virtually corrected the errors of the past.

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* *Chemical News*, lxx. 3.

† "Asphalt for Reservoir-linings," by P. W. Henry, *The Polytechnic*, Oct. 1897.

‡ *Engineering News*, March 22, 1900.

QUEEN LANE RESERVOIR, PHILADELPHIA, PA. LAYING ASPHALTIC MASTIC.
(Area covered 225,000 square yards.)

Mr. L. J. LeConte, who speaks from experience in such matters, considers that the fundamental principles to be borne in mind in all cases are as follows:*

(1) A reasonably firm foundation to support the lining is necessary; for, if the foundation yield too much under water-pressure, the lining is likely to be ruptured.

(2) The first coat should be liquid asphalt, so called, which has great penetrating qualities and enters freely into the foundation soil. This coating has adhesive qualities which are of great value, but on the other hand it is utterly lacking in ability to stand the sun heat.

(3) The second coat, the sun-proof coat, should consist of hard rock asphalt heated up to 300° F. and applied hot. This coating is both water-proof and sun-proof, but is lacking in adhesive qualities, and were it not for the first coat underneath could be taken up readily from the floor like a carpet. It is clear, then, that the first coat is simply a cementing material to hold the outer one in place.

A necessity arose, some years ago, of disinfecting the reservoir-lining at Buffalo, N. Y. A typhoid-fever epidemic of some magnitude was prevailing in the city at the time, caused by the entrance of the very foul water of a sewage canal into the public supply. As polluted water had unquestionably been pumped into the distributing-reservoir, it was determined to empty and disinfect the same before continuing its use. A very sharp discussion ensued among the local authorities as to the relative merits of chlorine and bromine for such disinfection, the latter having been already purchased for the purpose by the Board of Health.

As between the two agents proposed the author decided in favor of bromine.

Bromine-water was applied as a spray by the help of a fire-engine. The results were satisfactory.

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* *J. Am. Water-works Asso.*, xvi. 230.

A solution of "chloride of lime" would have been cheaper and probably as good, although not so easy to apply. Such a solution was used for the purpose of disinfecting the street-mains after the Maidstone epidemic of typhoid fever.*

As growing out of a consideration of reservoir-water, it is interesting to note the influence of the channels of distribution, i.e. conduits and city mains, upon the character of the supply. The differences between the following sets of samples, taken by the author at a city intake and drawn from taps at the other end of the town, show the changes in the water resulting from passing through the pumping system and street mains:

	Bacteria per Cubic Centimetre.	
	Intake.	Tap.
January 12	4,022	1502
February 5	3,322	436
April 10	17,665	2425
October 30	1,487	1090

It is instructive, and suggestive of the beneficial action of mains, to note that, for the year ending September 30, 1892, when the lake-water was pumped directly into the Chicago mains from the old short tunnel intakes, the percentages, by wards, of deaths from typhoid to total deaths were:

Wards less than two miles from the lake	6.0 per cent
" more " " " " " "	5.7 " "

At the time of testing the new filter for the city of Lawrence, Mass., the efficiency was found to be a removal of 98.3 per cent of all bacteria; but by the time the water reached the city hall 99.1 per cent had disappeared. Thus credit should be given the street-mains for the destruction of 0.8 per cent of the total germs.

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* *Engineering News*, June 21, 1900.

Similar evidence is presented by chemical analysis of water from the same town: *

	Albuminoid Ammonia.	Nitrogen as Nitrates.
Water as pumped to reservoir	.174	.135
Water from reservoir	.144	.146
Water from city tap two miles from reservoir	.117	.192

Currier gives the following counts of bacteria, showing influence of a flow of twenty-two miles in the Croton aqueduct:

Dobbs Ferry......... 453 per cubic centimetre
Central Park......... 175 " " "

Entirely similar results were obtained with the Mohawk River water by Professor Stoller, and the beneficial action of the Schenectady mains is graphically shown by him in the Thirteenth Report of the N. Y. State Board of Health.

In examining the Freiburg supply Tils found that the water from the reservoir contained fewer bacteria than that from the mountain source. But he also found that the bacteria increased in numbers after passing through the service-mains. Percy Frankland also found that the deep-well water furnished by the Kent Company contained fewer bacteria as it issued from the wells than when delivered by the city mains to the consumers. This is at variance with our experience in this country, and possibly the explanation is that the deep-well waters supplied a large amount of mineral food and thus encouraged bacterial growth.

* Rep. Mass. Board of Health, 1890.

CHAPTER VIII.

GROUND-WATER.

THE circulation of water in the soil is governed by gravity and surface-tension, and the latter is in turn affected by the structure of the soil, its composition, and the per cent by volume of the empty spaces between its particles.

The "voids" in the subsoils of South Carolina and Maryland, as determined by Whitney, show as a mean for twenty-three localities 48.73 per cent by volume, the extremes being 37.29 and 65.12.

The rate at which water will flow through a soil * is dependent not only upon the aggregate volume of the voids, but also, and more particularly, upon their separate dimensions; for it can be readily seen that the inhibiting influence of friction will rapidly increase with the fineness of the soil-grain.

This is seen in the following table, extracted from "Physical Properties of Soils." † The rates of flow through a certain depth are calculated for a uniform water-content of 12 per cent.

Soil (Maryland).	Number of Grains per Gramme of Subsoil.	Voids, per Cent.	Relative Time, Minutes.
Pine-barrens	1,692,088,503	40	8
Truck	3,342,323,489	45	16
Tobacco	8,258,269,975	50	33
Wheat	10,357,871,515	55	45
River terrace	11,684,097,513	55	49
Triassic	14,735,778,341	55	56
Helderberg	19,638,258,585	65	100

* In this connection see Wiley's "Agric. Anal.," i. 159.

† Bulletin 4, U. S. Depart. of Agric.

Storer gives the following values for the water-holding powers of various soils. The figures show the percentage of water absorbed in terms of the weight of the dry soil, and were determined by drying, weighing, soaking, draining, and again weighing each sample.

Quartz-sand, rounded edges	26 per cent
Quartz-sand with flakes of mica	32 " "
Gypsum (earthy)	27 " "
Loamy clay	50 " "
White clay	74 " "
Yellow clay	68 " "
Loam	52 " "
Fertile marly loam	59 " "
Limestone-sand	29 " "
Humus	180 " "
Peat	201 " "

A word of caution seems proper here. It must be remembered that the above figures show what the sands and soils will *hold*, not what they would *deliver*. No pump could extract that final portion of the contained water which would remain as "moisture," and its quantity would be a very respectable percentage indeed of the amounts given.

"When a soil is only slightly moist, the water clings to its grains in the form of a thin film. When these soil-particles are brought together, the films of water surrounding them unite, one surface being in contact with the soil-particles and the other exposed to the air. If more water enter the soil, the film thickens, until finally, when the point of saturation is reached, all the space between the soil-particles becomes filled with water, and surface-tension within the soil is thus reduced to zero. Gravity then alone acts on the water and with a maximum force.

"In a cubic foot of ordinary soil the total surface of the

soil-particles will be at least 50,000 square feet. It follows that when the soil is only slightly moist the exposed water-surface of the films surrounding the soil-particles approximates that of the particles themselves. If such a mass of slightly moist soil be brought in contact with a like mass saturated with water, the films of water at the point of contact will begin to thicken in the nearly dry soil at the expense of the water-content of the saturated mass. The water will thus be moved in any direction.

"During evaporation the surface-tension near the surface of the soil is increased, and the water is thus drawn from below. In like manner, when rain falls on a somewhat dry soil, the surface-tension is diminished, and the greater surface-tension below pulls the moisture down, even when gravitation would not be sufficient for that purpose." *

Wherever found, and under whatever circumstances, the water of the ground owes its origin to the rain or melting snow. Attention is called to this point because of a widespread notion that the wells of fresh water often existing in the immediate vicinity of the ocean are fed with sea-water from which the salt has been removed by percolation through the sand of the beach. Much to the writer's surprise, this inference is permitted in an engineering work of national fame. All along the shore of the Italian Riviera the traveller can see wells dug within 150 feet of the surf. In such cases the fresh water found originates some considerable distance inland, and the wells intercept it on its way towards an outlet in the sea; in other instances its origin is due entirely to very local rains, and its storage in the loose sand is owing to its being specifically lighter than the surrounding sea-water.

An instance of this kind is met with in the island of Muskeget, near Nantucket. The island is practically a mound

* Bulletin 4, U. S. Weather Bureau; also Wiley's "Agric. Anal.," i. 155.

of sand, raised but a few feet above the level of the ocean, and it is perhaps a mile in width. It was formed and is maintained by ocean currents, and is covered by a scanty growth of grass. Anywhere upon this island fresh water may be obtained by digging down two or three feet in the sand. Necessarily the water to be secured from such a source is limited in quantity. Under the general head of deep-seated water we shall see that fresh water may reach the ocean from very distant sources, and under a head so great as to cause a veritable "boiling spring" miles out at sea.

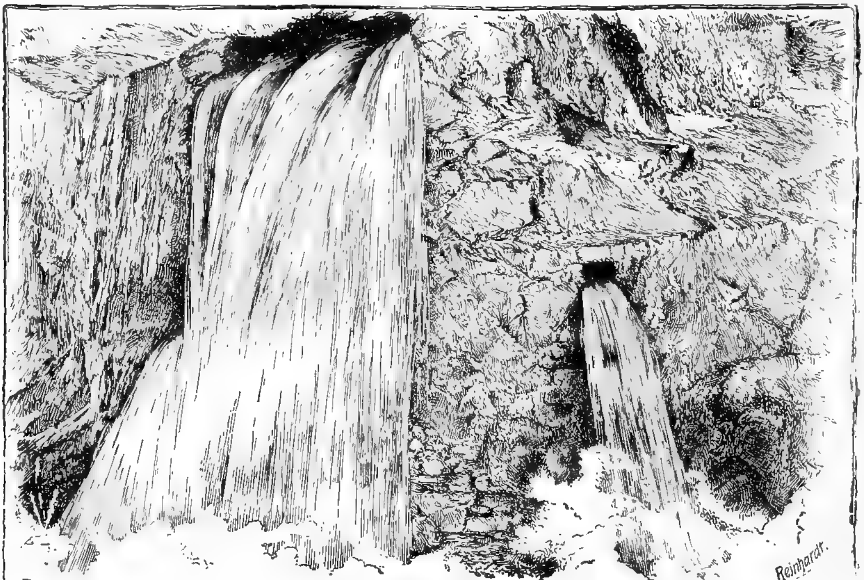
A commonly received conception of the occurrence of ground-water is that it moves in very definitely localized streams or veins, and that, to be successful, a well must be sunk so as to intercept one of these. Of course the conformation of the country may, at times, cause this popular notion to closely coincide with the truth, but a more general description of the occurrence of ground-water would be that of a widely extended sheet, and the expression "water-table" has been adopted with that view in mind.

Underground streams, some of large size, do certainly exist, especially in limestone districts, but their character would hardly permit of their being classed as typical "ground-water." If considered at all, they should be properly placed under "deep-seated water," although their importance as means of supply is entirely insignificant.

The mean height of this "water-table" (i.e., its distance from the surface of the ground) is governed by the average rainfall and the opportunities for local drainage. The delivery being into the rivers and streams of the district, or into the sea, there is always a slight inclination of the water-surface towards those natural drains, more especially in their immediate vicinity. The seaward slope of the water-table of the south half of Long Island, for instance, is from 8 to 12 feet per mile.

When a well is sunk into this layer of ground-water, and

draught by pumping made thereupon, a "cone of influence" is established, whose apex is at the bottom of the well, and whose lateral elements coincide with a new and steeper slope of the surface of the water-table. The steepness of this slope, and consequently the area of the base of the "cone," will in



ENG NEWS

UNDERGROUND STREAM ENCOUNTERED IN DRIVING TUNNEL FOR WATER-SUPPLY INTAKE, MILWAUKEE, WIS.

large part depend upon the character of the soil through which the water is caused to flow. If the grain of the soil be fine, the high degree of friction will greatly impede the passage of the water, and as a result the slope will be steep and the base of the cone contracted, while the reverse conditions would obtain in a soil of open, sandy texture.

Throughout the semi-arid region of the great Western plains the ground-water and deep-seated water development has received a very large share of attention indeed; for if it were true that the "underflow," which unquestionably exists there, constantly received inexhaustible reinforcements from the

mountains farther west, it would be very apparent that sterile wastes might quickly be transformed into fertile meadows by the sinking of wells and irrigation on an extensive scale.

It is erroneously held by many otherwise well-informed people that the ground-water supplying the wells of large portions of the great plains of Colorado, Kansas, Nebraska, Wyoming, and Texas is derived from the melting of the snow on the Rocky Mountains; but, as is shown in the reports of Professors Hay and Hill,* "the great body of the area of the plains is cut off from contact with the mountains by deep river-trenches, which make it impossible for them to receive any benefit from the melting of the mountain snows." This is shown graphically on the next page.

Referring to the "underflow" of the semi-arid region, Follett says:

"I was detailed to collect facts bearing on the possibilities of general irrigation from the underground waters. Many facts were gathered, all tending to confirmation of the assumption that the sheet-water, broadly speaking, receives none of its supply directly from the mountains. This is important, as tending to assist in computing the possible supply. Its source must be the western portion of the great plains, with very little, if any, foot-hill drainage. Here the rainfall is light, and the soil in general not such as will freely imbibe water, and the evaporation is rapid. All these conditions tend to show that the supply of underground water must be limited."

He concludes that—

"(1) The underflow is not supplied from the snow or rainfall of the mountains.

"(2) Its rate of movement in the sand is very slow, hence

"(3) The amount which may be drawn from it without permanently lowering its level is small.

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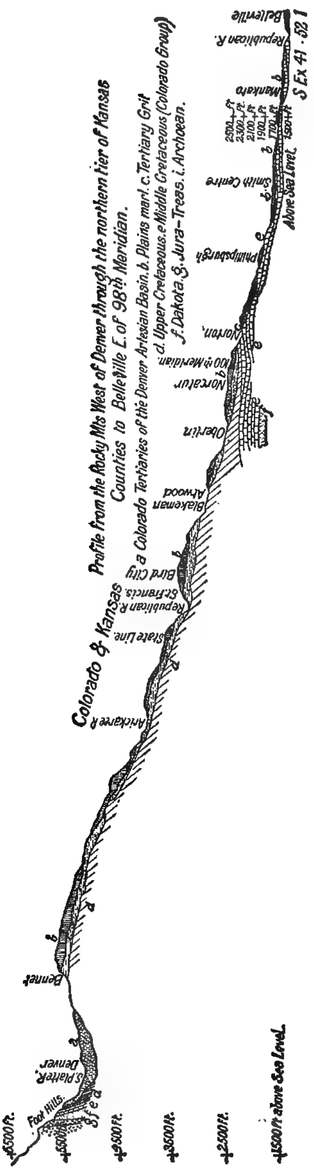
* Senate Doc. 41, part 3, 52d Congress.

"(4) Each farmer on the great plains whose land is underlaid by this sheet-water at a moderate depth can hope to obtain by pumping water enough to irrigate a small garden and truck-patch, say two to five acres, but



"(5) The supply is not such as to warrant large expenditures in constructing plants intended to obtain water sufficient for general irrigation. Even if momentarily successful, as a plant would be drawing down the surface of a lake with no outlet, the supply will be exhausted. In other words, the water-surface will be permanently lowered, and disaster to the irrigation-plant will follow.

"These conclusions are reached not only from a consideration of the facts here stated, but also by weighing many other known conditions."

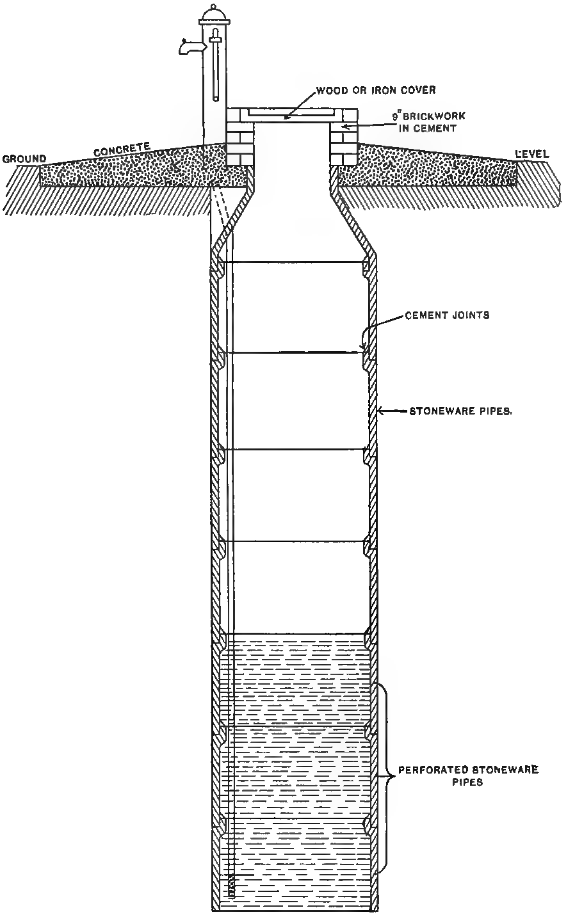
"Sunk wells" are at times formed by the caving in of the surface of the ground, and the consequent exposing of pools of water in a country apparently destitute of moisture. Such cavings are due to removal of soluble material from beneath the crust by the solvent action of the "underflow." Pools of this description have been formed in western Kansas.*

When the conditions prevailing in the district do not favor the de-

* Senate Doc. 41, part 4, 52d Congress, p. 30.

velopment of a spring on the side or at the base of a slope, the time-honored manner of tapping the underground supply is to sink the ordinary domestic well into the water-table.

To avoid surface contamination entering the well the construction illustrated herewith * is excellent. The well-top is



closed and is raised above the ground surface, while the joints of the tile-pipe casing are laid in cement down to the water-

* See *J. Sanitary Institute*, xxii. 515.

level. This arrangement insures a maximum filtering action of the intervening soil.

As illustrating what may be expected in the way of a ground-water from a locality beyond the reach of human contamination, the following analysis is given of a spring-water from the summit of the Catskill Mountains: *

Free ammonia	.01	per million	
Albuminoid ammonia	.06	"	"
Nitrogen as nitrates	.01	"	"
Nitrogen as nitrites	slight trace		
"Required oxygen"	.40	per million	
Total solids	110	"	"

A perfectly pure ground-water from Rensselaer County, N. Y., contains:

Free ammonia	.002	per million	
Albuminoid ammonia	.009	"	"
Nitrogen as nitrates	1.1	"	"
Nitrogen as nitrites	trace		
"Required oxygen"	.05	"	"
Chlorine	1	"	"
Turbidity	none		
Alkalinity	47.5	"	"
B. coli communis	none		
Total solids	140	"	"

It is not unusual to find waters of greatly varying characters at different depths in the same well, but such waters commonly flow from distinct and perhaps widely separated strata. The following case is of a somewhat different character. A city upon one of the Great Lakes sank a trial well upon a sandy peninsula extending some miles into the lake, in the hope of obtaining filtered lake-water therefrom.

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* The sample was taken during a prolonged drought.

METHOD OF RAISING GROUND-WATER FROM SHALLOW WELLS, TANGIER, MOROCCO.

Samples of water from depths of 29 feet and 57 feet were submitted to the author for analysis, with results as follows (parts per million):

	Samples from		
	29 feet.	57 feet.	Open Lake.
Free ammonia	0.280	too high to read	0.071
Albuminoid ammonia	0.189	too high to read	0.078
Chlorine in chlorides	1.500	61.0	5.000
Nitrogen as nitrates	trace	trace	none
Nitrogen as nitrites	0.0025	none	none
Required oxygen	5.350	10.1	1.750
Total solids	137.000	753.0	131.000

The sand appeared to be of the same quality throughout the depth of the well, except that the lower layers ran much higher in chlorides.

The two waters from the well differed not only from each other, but also from the water of the lake itself.

Water from the deeper portion of the well undoubtedly owed its character to the soluble material in the sand in which it had been stored, while that from the more superficial sand represented a dilution of the same by the more or less recent rainfall which rested upon the denser layer below.

A curious instance of the contamination of ground-water with mineral impurity is reported by Haworth.* In writing of Cherokee County, Kan., he says: "The well- and spring-waters before the mines were opened were first class, but as soon as the mines were opened all was changed, and the older the mines the worse the water. Animals of all kinds began to be seriously affected."

The mineral deposits of the section of country above referred to consist largely of zinc blende, and the development of the mining properties permits of a ready oxidation of the zinc sulphide to soluble salts. Zinc-bearing spring-water from

* *Am. J. Sci.* xliii. 418.

the neighboring portion of Missouri is reported as containing as much as 327 parts of zinc sulphate per million parts of water.

It is very well known that free sulphuric acid at times occurs in spring-waters of localities where pyrites is exposed to oxidation, and a very celebrated instance of such contamination has already been referred to.

Arsenic is occasionally a constituent of spring-water; and manganese associated with iron is quite common in the ground-waters of some districts, especially northwestern Missouri. In one water from that section of the country the writer found as much as 9.41 parts of carbonate of manganese per million parts of water. Most instances of the presence of metallic salts in water should, however, be classed under the general head of "mineral waters," and as such are here manifestly out of place.

For the delivery of large supplies the ground-water cannot be conveniently tapped by ordinary dug wells, so that recourse is had in such cases to what is known as "driven wells," set within suitable distance of each other, and coupled to a general main through which the water is drawn by the pump.

Each well is but an iron tube, perforated at its lower extremity, which is driven through the soil to the water-bearing layer below. Single wells of this description, surmounted by a simple hand-pump, may be seen, in some instances, replacing the domestic well in the country door-yard, but the type is more commonly met with in "gangs" of very considerable number for the supply of cities or towns.

A method of sinking them by the use of live steam was patented a few years ago, and, under some conditions of soil, may show considerable saving in first cost.

A hole some 20 feet deep is first bored with an auger, and in this is inserted a 6-inch heavy galvanized wrought-iron pipe,

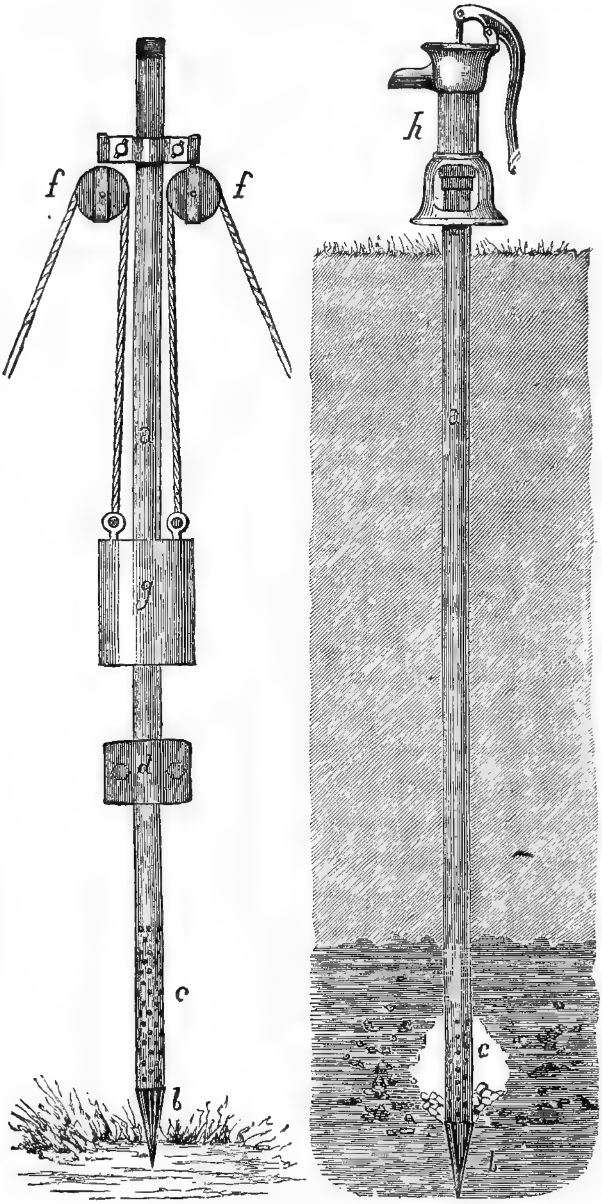
DRIVEN-WELL PLANT, BROOKLYN, N. Y.

its lower 6 feet being perforated with $\frac{3}{8}$-inch holes. Inside of this is placed a 2-inch steam-pipe, with a nozzle formed at its lower end, and steam at 150 pounds from a large boiler admitted. Sand, soil, stones, and steam escape from the 6-inch pipe in a continuous stream, and the pipe rapidly descends, being constantly turned by a man with heavy pipe-tongs at the mouth, and extra lengths added as necessary, until a supply of ground-water is found.

By whatever method the "driven well" is sunk, its mode of action is entirely similar to that of the common domestic well, from which it differs only in diameter, and it is supplied by the ground-water of the district in the same manner as its longer-known progenitor. There is, in short, nothing gained in the majority of cases from the supposed exhaustion of air by the action of the pump. Much has been claimed under this head, and it has been urged that the zone of influence always widens rapidly under "suction" from an air-tight well; but it must be remembered that "air-tight" is a term which can be usually applied to the well only, and not to the ground overlying the zone of influence. The porous soil will unquestionably admit all the atmosphere required, and consequently the flow of water will be determined by those forces, and those only, which govern in the case of wells of the ordinary type.

When, however, the well passes through an extensive layer of impervious clay, and taps a water-bearing stratum beneath, then the opportunities for a development of the advantages of "suction" reach their maximum.

Brooklyn, N. Y., is partly supplied with water by this system, and the attention of the public is often called to the results obtained there, but it must be borne in mind that the southern half of Long Island is pre-eminently suited to the driven-well system, it being but a sand-bank thrown up against an old glacial moraine, and that consequently it would not be wise to figure too closely upon such data for general practice.



DRIVEN WELL (FRENCH FORM). (GARBAN.)

At the first station near the Brooklyn end of the conduit there are 124 wells, each of a diameter of two inches. They are placed in two rows, twenty feet apart each way, and are forty to sixty feet deep. The tubes are perforated for ten feet from the bottom.

During a special trial of these wells the level of the local water-table was lowered eight feet by continuously pumping six million gallons daily for some time. This lowering of ground-water diminished uniformly in proportion to the distance from the wells, and entirely disappeared at two thousand feet away. A few observations were taken at another station where the water was drawn down fifteen feet, and the effect was noticed over a radius of twenty-five hundred feet from the wells.

Great dependence is often placed upon the driven-well system as being an arrangement by which pure water is guaranteed by the thoroughness of natural filtration on a large scale. There is one weak point in this view which must be always kept in mind and guarded against. The filter is a good one without question, but if damaged it is beyond repair and should be treated with corresponding care. The danger is that an additional supply is frequently sought for by an increase in pumping capacity rather than by an extension of the plant. As a result the wells are over-forced, there occurs undue lowering of the local water-table, rapid flow of water towards the exhausted locality causes channelways to form in the subsoil, and surface-water consequently enters the wells without suitable purification. Such a condition of things being once established, no remedy is available.

Writing about a large city plant, Breneman says: "Seven million gallons of water are daily drawn from a system of a hundred wells, varying in depth from 45 to 100 feet, and covering a line about 400 feet in length. Such a yield corresponds to a total rainfall of 32 inches a year upon 3000 acres, or, roughly,

represents the same annual rainfall upon all of the land within a radius of $1\frac{1}{4}$ miles from the pumping-station. Owing to the sudden demand for this water the soil-waters must be continually drawn downward in the vicinity of the pumps, and the nearer regions must be more effectually drained than the more remote. The predicted consequences are abundantly realized. Shallow wells in the neighborhood are wholly or nearly dry since the pumping-station has been opened. A swamp, formerly existing about the station, has been dried up. The subsoil of a cemetery, 370 yards distant, which offers frequent opportunities for observation, is said by the sexton to be much drier than heretofore."

A fact often lost sight of is that driven wells, so far as a permanent supply is concerned, are dependent upon the amounts of rainfall, "run-off," evaporation, and plant requirements. There is not, contrary to popular conception, an underground reservoir from which unlimited quantities of water may be pumped. It is true that a reserve storage exists, that may be drawn upon in time of drought, but Nature keeps a strict account of such matters, and the deficiency created in time of need must be made up during the period of plenty; otherwise the delivery of the plant will gradually diminish and ultimately entirely cease.

The result of heavy pumping was shown by the determinations of chlorine in the water from the old Liverpool wells. Lowering of the water-table, with infiltration of salt water from the river Mersey, was indicated, and at the same time evidence was presented, if such could possibly have been desired, that salt cannot be removed from sea-water by percolation through sand. (See page 322.)

Galveston, Tex., had a very expensive experience, showing the inability of sand to freshen sea-water. The citizens of that town attempted to extend an excellent driven-well plant which they possessed by increasing the number of wells, and

NEWTON WATER-WORKS — 5 FT. × 4 FT. 8 IN. WOODEN COLLECTING CONDUIT, 1890.

they carried the draught upon the ground-water beyond the point of normal supply. As a result the entire system was damaged by the inflow of salt water from the Gulf.

One very material advantage possessed by a driven well over a dug one is that it can be sunk deeper in the water-bearing sands at small expense, and, with a long strainer, can take water throughout a great fraction of its length. A dug well, on the other hand, has its construction hampered after water is reached, and its cost per foot is greater beyond that point; so that it commonly has to depend principally upon its bottom for supply, tapping, as it does, only the upper portion of the ground-water layer.

When preparations are being made to sink a gang of driven wells, consisting of a considerable number of individuals, one of the first questions that must be considered is the distance apart the wells should be placed so as not to draw from one another's territory. This is a point upon which no fixed rule can be given. In the Brooklyn plant, to which reference has been made, the wells are twenty feet apart, but the local conditions may cause this distance to be materially increased in some cases. It is often poor economy to place wells nearer than fifty feet from each other, and at times even one hundred feet may be the suitable distance.

A good practice to follow would be to sink two wells at what judgment would indicate as a proper interval, pump from one of these, and, if the second be too much affected by such pumping, increase the distance for the third well, and so on until the proper distance be determined.

Closely related to the well systems already spoken of, the "infiltration-gallery" stands as a widely used method for securing the water of the ground.*

Such a gallery is really but a dug well with one very long

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* See page 174.

horizontal axis. Its position is usually near, and parallel to, the banks of some stream, such a site being chosen with a view of securing its supply from the water of the river. Except under unusual circumstances, however, the water reaching the gallery comes from the landward side, and is the ground-water of the district for which the river is the drain.

Rivers may indeed diminish in volume as they flow onward, and may even entirely disappear by sinking into the ground, as is the case with a number of streams flowing down the slopes of the Rocky Mountains, but this condition is distinctly exceptional. A river is commonly to be considered as a drain, into which water is received, but from which none flows. To such an extent is the bed of a river usually rendered impervious to the outward passage of water by the accumulation of fine silt that an old authority quite covers the case when he says: "If you dug a well in the middle of a river, and kept out the surface-water, it is doubtful if you would get the river-water in your well."

The writer found the following results for water from a well sunk upon a sand-bank in a river, and for water from the river itself:

	River.	Well.
Free ammonia	.045	.045
Albuminoid ammonia	.155	.095
"Required oxygen"	6.	2.7
Chlorine	2.9	4.3
Nitrogen as nitrates	.337	.127
Nitrogen as nitrites	0	0
Total residue	131	100.5

Also the following results for the water of a small filtering-gallery within twenty feet of a large river, compared with the water of the river itself:

	River.	Gallery.
Calcium carbonate	26.8	163.0
Calcium sulphate.	19.4	80.0
Magnesium carbonate.	0.0	38.6
Iron.	0.7	2.5
Chlorine (as chlorides).	4.0	22.0

Mr. Denman, in speaking of some very successful galleries at Des Moines, says:

"We are favored by nature in being able to take water from the valley of the Raccoon, which is surrounded on either side by high hills, not less than one hundred and fifty feet high; and in the valley there is sand and gravel of great depth.

"We do not perceive any of the river-water in the supply in our galleries, although they are laid in the middle of the river. When the section of gallery was crossing the river, looking inside we failed to detect any water dripping from the top, although the river was flowing over it and only twelve feet above. The water from the galleries is much colder than that from the river."

Dependence is constantly laid upon the excellent filtering powers of these underground galleries, and they justify it during the earlier periods of their use, but, considered as a filter, such a device is beyond cleaning and repair; it may clog, or, on the other hand, ruinous channelways may follow heavy pumping. In the first instance no water, and in the second instance polluted water, may result.

A rather odd method of securing ground-water may be seen in connection with the public supply of Messina, Sicily.

A four-mile tunnel on the railroad between Messina and Palermo is used to reinforce the water system of the former city. The tunnel has its highest point in the middle, so that in reality only half its length is available for catching water. The natural drip from the rock is collected in open side gutters.

and is thence conducted to increase the general storage. Of course the water so caught is exposed to the impurities common to railroad tunnels.

As concerning the question of pollution of ground-water, an important paper was read and discussed in London on the influence of different kinds of soil on the cholera and typhoid organisms. The following is taken freely from the report: *

"The research was undertaken with a view to answering the following question: Had the soil in itself any action favorable or injurious to the life of the comma spirillum of *cholera Asiatica* and the bacillus of typhoid fever, or did the length of life of these organisms in soil simply depend upon the amount of moisture that might be present? The action of the saprophytic bacteria present in the soil was left out of consideration. Sterilized soils alone were used. The experiments were carried out with white crystal sand, yellow sand, garden earth, and peat. These were sterilized by means of moist heat. In white crystal sand comma spirilla were alive on third but dead on fourth day; in yellow sand, alive on third but dead on fourth day; in garden earth, alive on third but dead on fourth day. The comma spirilla must have died, therefore, between the third and fourth days. Experiments were next made with a moist soil, which, however, contained no excess of moisture. In moist white crystal sand comma spirilla were alive on the seventh day; in moist yellow sand comma spirilla were alive on the thirty-third day; in moist garden earth they were alive on the thirty-third day.

"Experiments were made to find the length of time comma spirilla would live in a soil when any excess of moisture was allowed to pass through the soil, but where little or no loss of moisture took place from the surface. Under such

* *Medical Record*, June 23, 1894.

conditions the spirilla were alive in white crystal sand on the twenty-eighth day, in yellow sand on the sixty-eighth day, and in garden earth on the sixty-eighth day. In a soil deprived of its moisture the comma spirilla did not live longer than one to two days. In white silver sand, when moisture was allowed to escape, the spirilla were alive on the third day, but dead on the eighth day; but if evaporation of water was prevented, the comma spirilla were alive on the forty-seventh day. In white crystal sand, where evaporation was allowed to take place, the spirilla were still alive on the twenty-seventh day with 1.57 per cent of moisture in the sand. The spirilla were dead on the thirtieth day with 0.66 per cent of moisture in the sand. When evaporation was prevented, the spirilla were alive on the one hundred and seventy-fourth day, and the sand still contained 7.1 per cent of moisture, showing a close relation between the amount of moisture in the soil and the length of life of the organisms. With regard to peat, it was found that the comma spirilla were invariably dead in twenty-four to twenty-six hours, independently of the amount of moisture that might be present.

"Next as to the bacillus of typhoid fever on a dry soil where evaporation was allowed to take place: In white crystal sand the bacilli were found up to the ninth day, in yellow sand up to the eighteenth day, and in garden earth up to the fourteenth day; but in moist crystal sand the typhoid bacilli were alive on the twenty-third day, in yellow sand and in garden earth on the forty-second day. On soils which had been deprived of their moisture the bacilli were only found up to the seventh day.

"Experiments made with peat showed that on this soil the bacilli did not survive longer than twenty-four hours. Peat was the only one of the four soils used which exercised a distinct destructive action on the organisms, independently of the amount of moisture present. Experiments made to test the

filtering capacity of the soils showed that with a filter six inches thick white crystal sand held back 99.6 per cent comma spirilla, yellow sand held back 99.9 per cent comma spirilla, garden earth held back 89 per cent comma spirilla, and peat held back 100 per cent comma spirilla. On the other hand, a current of water could carry the comma organisms through two feet and a half of porous soil. Conclusions: White crystal sand, yellow sand, and garden earth had no marked action on the organisms, their length of life in the soil depending chiefly on the amount of moisture. Peat, on the contrary, was very deadly to both the comma spirillum and the typhoid bacillus. The soil acted as a good filter, holding back most of the organisms; but it was possible for them to be carried through two feet and a half of porous soil by a current of water."

The action of the common saprophytes in the soil is known to be prejudicial to the growth of the cholera germ, and, as these ordinary bacilli are more plentiful in the upper layers of the soil, it is interesting to note the observation of Sternberg that "the cholera spirillum in the months of August, September, and October grew at a depth of nine feet in the soil, but in the remaining months of the year failed to grow at six feet, although growth occurred at four feet."

This seems somewhat of a contradiction, unless it be meant that the spirillum fails to reach the stated depth after passing through the upper soil-layers.

Sternberg also found that the bacillus of typhoid fever "grew at a depth of nine feet during the greater portion of the year."

A bacteriological examination of the soil of Philadelphia was made by M. P. Ravenel with the following conclusions: *

The greatest depth at which bacteria were found in virgin soil was six feet. All samples below this depth were found to be sterile.

* Memoirs Nat. Acad. Sci., vol. viii.

No samples of "made soil" were obtained from a greater depth than nine feet, but the bacteria at that depth seemed to be as numerous as at the surface.

There is a greater probability that "made soils" may contain pathogenic bacteria.

The opportunity for the contamination of well-water, particularly that of the common domestic well, is often very great. No proper conception of the right location for the house-well ever seems to enter the minds of most of our rural people, and if water can be had from a spot conveniently near for general housework, inquiry as to the quality of such supply is usually considered quite superfluous. The author has elsewhere referred to an instance where the well was entirely covered by a huge manure-heap.

In their Sixth Report the English Rivers Pollution Commission state the case quite graphically:

"The common practice in villages, and even in many small towns, is to dispose of the sewage and to provide for the water-supply of each cottage or pair of cottages upon the premises. In the little yard or garden attached to each tenement or pair of tenements two holes are dug in the porous soil; into one of these, usually the shallower of the two, all the filthy liquids of the house are discharged; from the other, which is sunk below the water-line of the porous stratum, the water for drinking and other domestic purposes is pumped. These two holes are not infrequently within twelve feet of each other, and sometimes even closer. The contents of the filth-hole or cesspool gradually soak away through the surrounding soil and mingle with the water below. As the contents of the water-hole or well are pumped out they are immediately replenished from the surrounding disgusting mixture, and it is not, therefore, very surprising to be assured that such a well does not become dry even in summer. Unfortunately excre-

mentitious liquids, especially after they have soaked through a few feet of porous soil, do not impair the palatability of water, and this polluted liquid is consumed from year to year without a suspicion of its character, until the cesspool and well receive infected sewage, and then an outbreak of epidemic disease compels attention to the polluted water. Indeed, our acquaintance with a very large proportion of this class of potable waters has been made in consequence of the occurrence of severe outbreaks of typhoid fever amongst the persons using them."

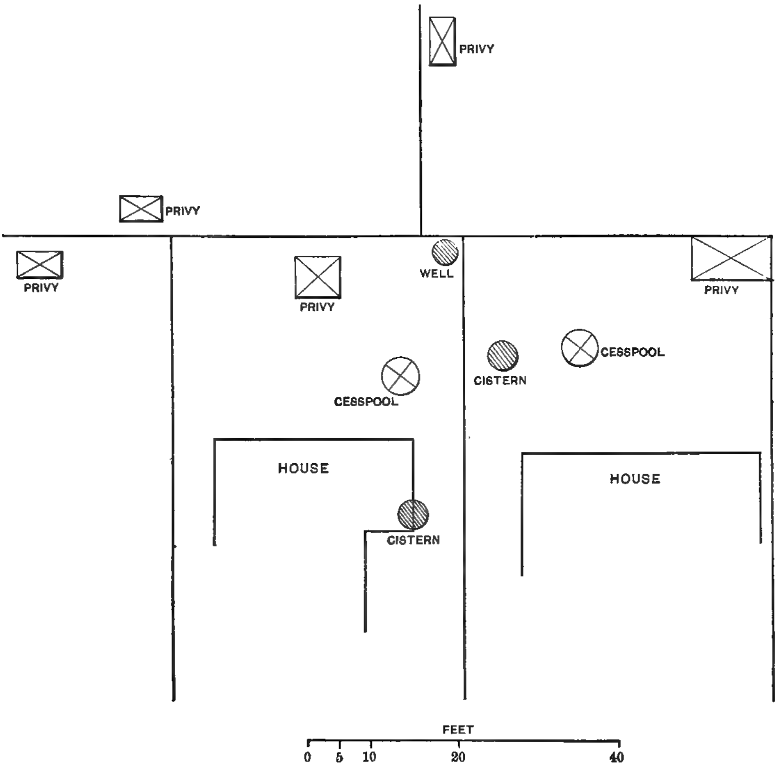
The reckless manner in which a domestic well is frequently surrounded by sources of great pollution is here shown in an illustrated form from a Rhode Island case reported by E. W. Bowditch. (See top of page 347.)

Although not so aggravated an instance as the above, yet the following case is sufficiently bad to justify hearty condemnation. The well, which, with its surroundings, is shown in the following plan, is on Green Island, N. Y., and its water, which is in daily use, is doubtless responsible for the typhoid fever occurring in the neighborhood. The water-table slopes toward the well. (See bottom of page 347.)

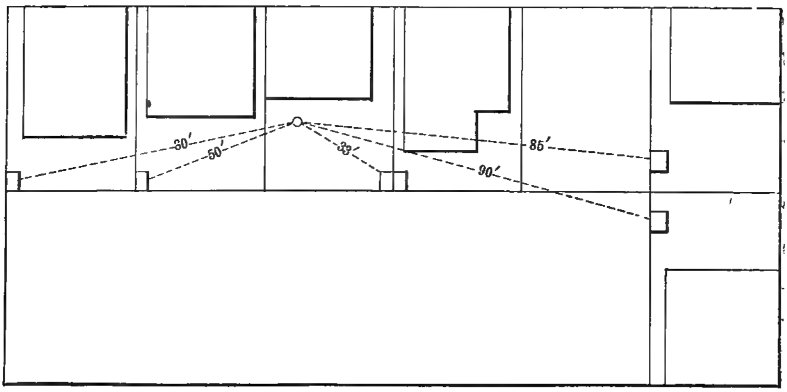
The analytical results of this water show very low "ammonias," but exceedingly high "chlorine" and "nitrates," adding further weight to Mallet's decision that a knowledge of the amount of "nitrates" is especially valuable for arriving at a correct judgment as to the quality of a water:

Free ammonia	.01
Albuminoid ammonia	.02
Chlorine	70.00
Nitrogen as nitrites	trace
Nitrogen as nitrates	15.00
"Required oxygen"	.10

One public well, which the author succeeded in having closed after much difficulty, was fouled by cesspool infiltration



WELL SURROUNDED BY PRIVIES—RHODE ISLAND.



WELL AND SURROUNDINGS—GREEN ISLAND, N. Y.

to a large extent, yet because of the coolness and sparkle of its water it was widely popular, so much so that its final closing had to be accomplished after midnight to avoid resistance.

As an instance of excessive pollution the following analysis is given of a well-water from Southampton, England.* The water was "in daily use for all domestic purposes, was fairly presentable to the eye, and not unpalatable. Under the microscope it showed starch-grains, paper, and animal hairs."

Free ammonia	56.800
Albuminoid ammonia	.332
Nitrogen in nitrates	19.026
Chlorine	22.000
Phosphates	heavy traces
Total solids	417.000

Unattractive as this English picture is, we can certainly match it in America; and in some cases the unsanitary arrangements causing the trouble receive more or less support from the law.

In many of the towns of Ohio the local boards of health determine the minimum distance to be allowed between a well and an uncemented privy-vault, and such distance is most commonly fixed at fifty feet. The permitted distance for the town of Norwalk, a place of 8000 inhabitants, is twenty-five feet. At Bond Hill the minimum distance allowed is twenty feet! †

That any such distance of soil-filtration can protect a well from pollution, provided the polluting source be constant in character, is beyond even hoping for, and many instances could be given showing how even considerably greater distances have also failed.

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* *Analyst*, vi. 65.

† See Report Ohio Board of Health for 1892.

As serious a case of contaminated ground-water as can be quoted will be found in the record of the Maidstone typhoid epidemic.* It appears that the city contains 30,000 inhabitants, and draws its water from a subsoil source stored beneath a loamy clay. During the "hop" season some five hundred "hop-pickers" established themselves in rude shanties upon the catchment area whence the local ground-water was reinforced by rainfall. Testimony showed that some ill people were among these laborers, and that there existed no sanitary conveniences whatever.

An unusual drought had occurred, which caused deep cracks to open in the stiff soil, so deep that the health officer thrust his cane into some of them without finding bottom.

Later there was a heavy fall of rain which washed surface filth into these fissures and produced a material rise in the ground-water. Of course there was lack of efficient soil-filtration.

"At the end of nineteen days there had been no less than 1172 cases of typhoid fever and the trouble was still holding its own at the rate of seventy-six new patients a day."

Somewhat similar is the instance of the typhoid outbreak at New Harrington which resulted in 275 cases and 26 deaths.† It appears that soil-cracks, due to subsidence caused by coal-mines in the neighborhood, permitted direct flow from farm-house privy-vaults through some underground feeder to the town well situated some three quarters of a mile away.

Extract is here made from a report of the writer's upon the question of closing certain city wells:

"As is well known, there are a number of street-pumps in this city, and the water which they supply is cool, sparkling, brilliantly clear, and generally relished. The ground into which these wells are sunk is the old river flood-plain, which

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* *Analyst*, xxiii. 142.

† Report of British Med. Asso. See "Water-borne Typhoid," Hart.

extends from the present river to the eastern hills. Into this same soil pours the drainage from many cesspools and privies, and the slope of the ground in the centre of the city being away from the river, the natural drift of the ground-water toward a western outlet is to an extent impeded. In consideration of these few facts, can any reasonable person expect to get pure water from such a source?

"It is a fatal error to fancy that because a water has a bright, sparkling, clear appearance and a pleasant taste, therefore such water is wholesome. Carbonic acid gas is what causes the brilliancy and refreshing taste of a ground-water, and to the solvent action of that gas is due the clearness of many waters which hold much organic matter in solution. When it is borne in mind that carbonic acid is one of the products of sewage decomposition, the inference as to its possible source in the case of the present well-waters is not a pleasant one. During the last four years I have at different times examined the waters from several of these wells, and am persuaded that they are contaminated with sewage material beyond a peradventure.

"It is hopeless to depend upon the purifying influence of the intervening soil to protect the wells from privy and cesspool fouling, because soil-filtration, in order to be effective, must be *intermittent*. That is, after a 'dose' of sewage has been added to a soil (and the 'dose' must not be a large one) opportunity for thorough aeration of the soil must follow, or the second 'dose' cannot be purified. With a constant flow of polluting material the purifying powers of the soil quickly cease to act.

"It will be objected that these well-waters have been in use for many years without bad results following. Possibly; but it must be remembered that the imbibition of sewage derived from healthy sources may be quite harmless unless it be in too concentrated a form, however undesirable it may be

from an æsthetic standpoint. This has been experimentally proven many times. The serious part of it all is that the sewage which contaminates the well-water may, during an epidemic, suddenly become pathogenic in character, and then the well becomes a distributing centre for disease. A city well is always to be suspected, and if, upon examination, its water is found impure, it should be forthwith ordered closed, particularly under circumstances such as threaten cholera invasion."

As illustrating how unexpectedly a good ground-water may become damaged on its way to the point of consumption a case recently observed by the writer while in New Jersey is worthy of mention. The well was found in good location and furnishing excellent water, but the pump-main was laid to the house by way of a somewhat distant stable, on top of which was the windmill supplying the power necessary to raise the water. The objectionable analytical results were found, upon investigation, to have been due to defective pump connections and infiltration of stable drainage.

Some time since the Medical Society of the District of Columbia submitted to the House of Representatives a valuable report, with numerous charts, showing the prevalence of typhoid fever in the capital and its relation to the use of water from the street wells.

"We know that water from the 310 pumps existing at the time of the report of 1889 was largely used by the people living on the 426 squares in which the 626 fatal cases occurred. Even by those having access to Potomac water well-water is largely consumed, on account of its being colder during the hot months of the year."

The committee of the medical society having the investigation in hand divided the city arbitrarily into five sections, and then found the following relations existing between the number

of street wells in use in each section and the corresponding number of fatal cases of typhoid fever: *

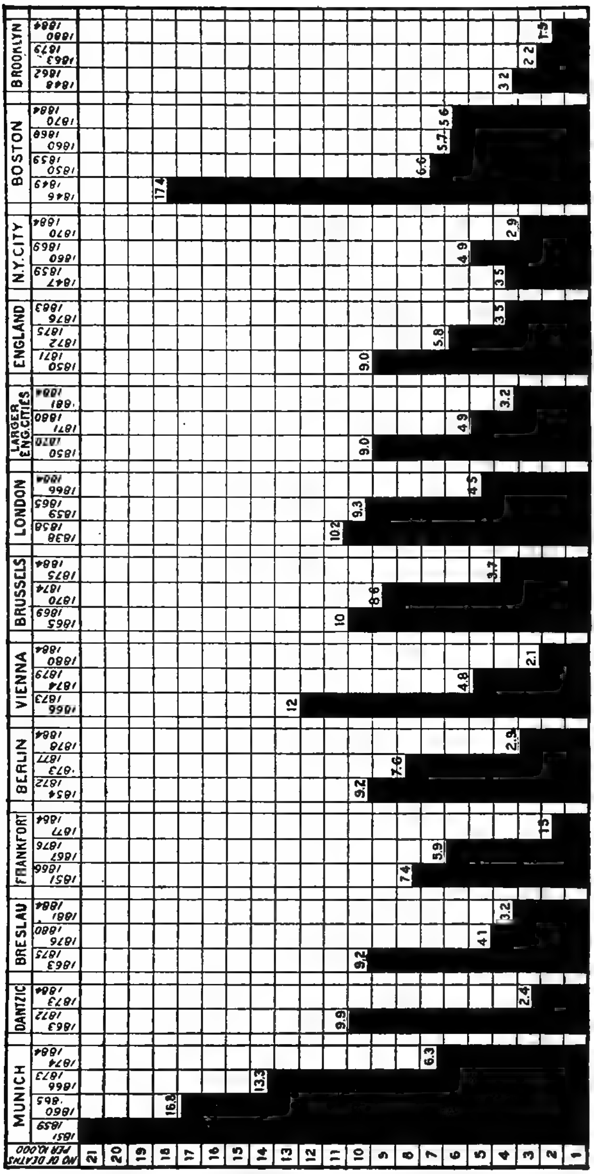
Deaths from Typhoid.	Number of Wells.
197	140
179	70
114	34
84	47
52	18

To obtain the approximate number of total cases of illness from typhoid the number of fatal cases should be multiplied by ten. The relation shown in the above figures is quite striking.

It would not be amiss, perhaps, to refer to another point strongly illustrated in the Washington report above quoted, but before giving the numerical data the report contains the reader is asked to bear in mind what has been said in another chapter concerning the recent investigations of Sanarrelli, which point to a relation between bad hygiene and susceptibility to typhoid fever.

This work of Sanarrelli's is of great importance as filling a gap long felt, and harmonizing to a great degree the hitherto opposing theories of "ground-air" and "water-supply" as causes of typhoid fever. As so often happens, the middle course has proved the correct one, and the two theories are found to be complementary rather than in opposition. Petterkofer's "ground-air" introduces the insanitary conditions suited to the speedy development of the typhoid germ should it arrive with a contaminated water-supply. The Washington report lays special stress upon the fact that good water and good sewerage should go hand in hand if typhoid is to be

* In this connection see also "Analysis of Washington Well-water," by Richardson, *J. Anal. Chem.*, v. 23.



DEATHS FROM TYPHOID FEVER TO EACH 10,000 INHABITANTS BEFORE, DURING, AND SINCE THE INTRODUCTION OF SEWERAGE AND WATER-SUPPLY. (AFTER E. F. SMITH, MICHIGAN STATE BOARD OF HEALTH.)

avoided, and in the light of what we know to-day the point is unquestionably well taken. (See page 353.)

The city of Dantzic received its good water in 1869, but the typhoid death-rate was not materially improved until 1872, when the city was sewered. Vienna showed the opposite condition; an excellent sewerage system, but a bad water-supply, had existed previous to 1874, and the annual typhoid death-rate ran as high as 34 per 10,000 of population. In 1874 water of very superior quality was introduced, and in three years the typhoid rate had fallen to 1.1. We thus see that good sewerage alone is not all that will be required for desirable sanitary results.

"In Munich from 1854 to 1859, when no means existed to prevent the fouling of the soil, the mortality was 24 to 10,000 inhabitants. From 1860 to 1865 the sides and bottoms of the pits of the privies were cemented, and the mortality fell to 16.8. From 1866 to 1873, with partial sewerage, the rate was 13.3; from 1874 to 1880, with improved sewerage, it was 9.26; and from 1881 to 1884, with still greater improvements, it fell to 1.75 per 10,000 inhabitants.

"Typhoid fever increases in proportion to the saturation of the soil with decomposing organic matter, especially human excreta, and to the drinking of infected well-water.

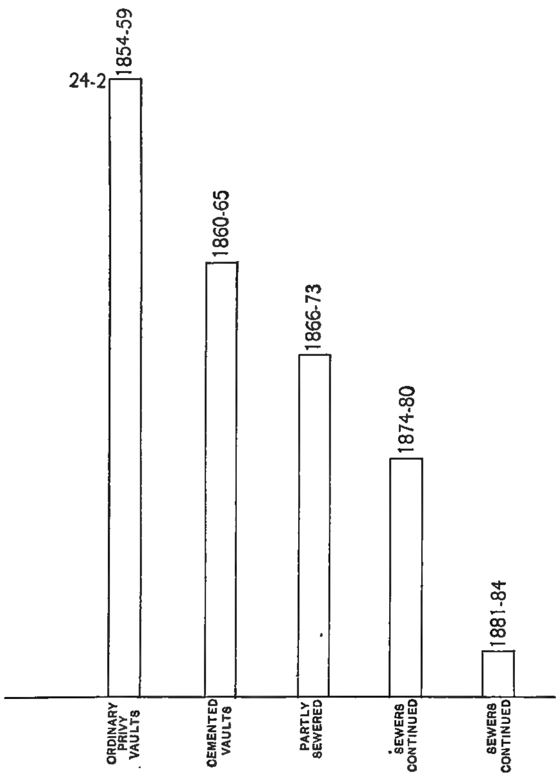
"Typhoid fever decreases in proportion as a city is well sewered, and in proportion to the abandonment of the drinking of well-water * and of all contaminated water."

These are the carefully considered conclusions of the Washington committee, after a very painstaking investigation, and they are graphically supplemented by the chart, on page 355 which abundantly explains itself.

In view of general observation and experience the author is strongly of the belief that seepage from the privy-pits into

* City well-water is of course intended.

the domestic well is the cause of typhoid fever being largely a country disease; and he is interested in the passage of a law doing away with such vaults entirely. Some means of frequent removal of excrement, either by burial in safe and successive spots, as is possible upon a farm, or by transportation to a dis-



CONDITIONS OF SEWERAGE AND TYPHOID-FEVER DEATH-RATES (PER 10,000 INHABITANTS) AT MUNICH. (AFTER BAKER.)

tance, as can be arranged for by a country town, should be insisted upon by law. Economy of both purse and labor is now accomplished by virtually depositing much of such material in the family well.

"In order to ascertain to what extent soil was contaminated by privy-vaults I dug down near a privy-vault which

was situated on the outskirts of the town and isolated, so that there were no other known sources of contamination around; I dug down a foot behind this privy-vault and took up some soil three feet below the surface to determine the amount of organic matter in it; then I went off 6 feet and did the same thing, then 12, then 18, then 24, then 30; and, without going into detail, suffice it to say that the contamination of the soil from that single privy, built upon nearly level ground, could be detected 50 feet from the vault plainly. This was determined by comparing the amount of organic matter in these different samples of soil with other soil of the same kind where there were no known sources of contamination." *

An excellent way to determine the probability of objectionable drainage material entering a well is to place a quantity of a solution of common salt, of lithium chloride, or of fluorescein ($C_{20}H_{12}O_5$) at the point whence contamination is supposed to come. The normal composition of the water being known, there will appear an increase in "chlorides," a spectroscopic test for lithium, or a decided fluorescence in the water if there be drainage from the source in question.

It may be worth mentioning here that English and American laws are entirely at variance with one another regarding the ownership of underground percolating water, i.e., "ground-water."

Such ownership became definitely settled in England in 1859 by a decision in the case of Chasemore *v.* Richards, in which the judgment of the House of Lords was unanimous. "They held that the principles which regulate the right of owners of land in respect to water flowing in known and defined channels, whether upon or below the surface of the ground, do not apply to underground water which percolates through the strata in no known channels."

* Vaughan, Ypsilanti Sanitary Convention, July, 1885.

The principles laid down in this case have never been shaken or departed from. In every case that has arisen since then, the difficulty has been, not whether the decision in Chasemore *v.* Richards was right, but rather in its application to the facts of the particular case.

In the late decision of the New York Court of Appeals regarding rights in underground water, in the case of Forbell *v.* the City of New York, the decision grants damages to a market-gardener for the diversion of underground water from his land and enjoins the city from continuing to divert the water.

The plaintiff owned farming land in the 26th Ward of Brooklyn, within about 2000 feet of the Spring Creek pumping-station belonging to the water-supply plant. He worked a market-garden and claimed that the operation of the driven wells at Spring Creek reduced the natural flow of water in ditches across his land and caused the failure of crops. Justice Smith of the Supreme Court decided in favor of the plaintiff, and awarded him $6000 damages The city carried the case to the Court of Appeals, which now sustains the decision of Justice Smith as to damages and also grants a perpetual injunction restraining the city from operating its driven wells at Spring Creek. The court practically decided that if the city wanted water from driven wells, it must condemn and buy all the surface land affected.*

* See *Engineering News*, Dec. 6, 1900.

CHAPTER IX.

DEEP-SEATED WATER.

SPRINGS of small flow, such as trickle out of the country hillside, are properly classified with the shallow wells already spoken of; they furnish "ground-water" only and are of local origin.

Quite another matter, however, are those natural fountains which reach the surface in very great volume, possessed of a temperature radically different from that of the local subsoil, and holding in solution mineral materials that may be quite foreign to the neighborhood. Such water is always of distant source, and the gathering-grounds where it originally falls as rain may be very far away indeed.

Picture the outcrop upon some rainy upland of a porous stratum, encased upon either side by strata impervious to water; let the strata be possessed of a moderate dip, then let them be cut transversely at some point below, either by simple erosion or by a geologic fault, and the conditions for a deep-seated spring would be complete. Rain-water falling on the distant outcrop would pass down the porous stratum, picking up soluble material on the way, and would escape as a spring at the point where the strata were broken or eroded.

Very notable springs due to geologic faults occur with frequency, but to Americans the best-known instance is to be found at Saratoga, although the water furnished is medicinal rather than potable, and therefore beyond our present consideration.

At the head of San Antonio River, not far from the city of San Antonio, Texas, is situated a mammoth spring of pure water, whose daily outflow is some fifty million gallons. This spring is but one of a group of great springs which "coincide almost exactly with the line of the great Austin Del Rio fault."*

A very curious instance of a spring of great magnitude caused by erosion cutting into the water-bearing stratum is to be found several miles out at sea off the coast of Florida, east of Matanzas Inlet.

There are reasons for believing that the Matanzas spring is due to a bursting of the confined waters through a hole in the upper hard rock-layer. Successful sounding has recently been accomplished in the spring itself. In its immediate vicinity the ocean suddenly deepens from a depth of 60 to one of 126 feet.

A shipowner familiar with the locality informs the writer that the volume of water boiling up in the ocean at the site of the spring is so large as to prevent a boat remaining on it for more than a moment, as "the boat is washed off from it as from the rapids of a river." The same authority describes the odor of the water as that of a sulphur spring, which is an additional point showing its kinship to the artesian waters of Jacksonville and St. Augustine.

There are several other springs on the same coast similar to this, although not so large.

Fresh-water springs occur in the North Sea in the vicinity of the islands surrounding Holland, and are situated two or three miles from shore. "Similar springs may be found in the Adriatic Sea, near Fiume, Abazzia, Triest, and in other places, so that the surface of the sea is slightly raised up and a whirlpool may be observed." †

While confidence is seldom misplaced in the freedom of

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* Senate Doc. 41, 52d Congress.

† Trans. Am. Soc. C. E., xxx. 300.

deep-spring water from surface pollution, instances are not unknown where streams, or portions of them, disappear to rise again after subterranean flow, thus masquerading as true deep-seated water.

The "source de la Loue," the largest "spring" but one in France, with a flow of 15,000 litres per second, furnishes an illustration of the kind; the discovery of the true character of the water having come about by accident in August, 1901.

It seems that a fire occurred in an absinth manufactory located upon the banks of the river Doubs, some seven miles distant from, and at a greater elevation than, the "spring," whereby great quantities of absinth escaped into the river.

About forty-eight hours later the water of la Loue gave unmistakable evidences of the presence of absinth.

The conclusion is that the spring represents, at least in part, a subterranean branch of the river Doubs. The outflow from la Loue again joins the Doubs lower down.

Instances are by no means rare of the use of deep springs for water-supplies of magnitude, such as the "Vanne" water, which supplies a part of Paris from springs in massive chalk near Troyes, but deep-seated water is much more commonly reached by special borings.

It would be going too far to undertake a description of the process of drilling these deep wells, yet there are certain facts concerning their cost and rapidity of construction, given us by Professor Carter,* which may properly be here inserted:

"The most difficult rocks to drill through are trap, quartzite, compact fine-grained sandstones, certain clay slates, granites, syenites, and compact hornblende schist, obsidian, etc.

"The softer rocks, such as talcose and chlorite schists,

* *J. Fk. Inst.*, September, 1893.

serpentine and other magnesian rocks, limestone, dolomite, hydro-mica schists, and many coarse-grained sandstones, are readily drilled through. The following table will show the thickness of rock pierced by a chisel drill 20 feet long, $5\frac{5}{8}$ inches in diameter, weighing 700 pounds, guided so as to make a round hole:

Locality (Pennsylvania).	Rock.	Rate.		
Duffield's farm, on Stony Creek, near Belfry,	Clay slate (Trias)	$4\frac{1}{2}$ ft.	drilled in	10 hours
Ice company's well, Norristown...	Sandstone (Trias)	5	"	"
Kunkle's farm, Valley Green Road, near Flourtown	Limestone (Silurian)	$5\frac{1}{4}$	"	"
Wheadley's farm, Chester County	Hydro-mica schist	7	"	"
Wm. Janeas' farm, near William Station	Sandstone (Potsdam)	10	"	"
Roberts' well, Spring Mill..................	Sandstone (Potsdam)	$18\frac{1}{2}$	"	7 hours

"The minerals which compose a rock may be very hard, and yet the cementing material may hold the grains so loosely that the drill will make rapid progress through the rock. Sandstone, when composed entirely of silica, or when the cementing material is gelatinous silica, as in quartzite, is extremely hard to drill, but when the cement which binds the grains is feldspar, which decomposes readily, then the grains are loosely held, and the rock is readily drilled.

"The price of drilling is about $2 per foot in Montgomery County, Pa., for wells six inches in diameter and from 100 to 200 feet deep; this is independent of the character and hardness of the rock.

"Other contracts in Philadelphia have been made at the rate of $2.75 per foot for drilling down to 500 feet, and $3 per foot for drilling below a depth of 500 feet; this does not include the iron pipe for casing, but only the drilling. The six-inch iron pipe (internal diameter five and five-eighths inches) which is used to line the well varies in price from forty to fifty-five cents per foot."

Wells are sunk through the shales and conglomerates of the Catskill Mountains, but not to great depths, at the rate of $2 per foot, and in the Hudson River shale of the upper valley

at from $1.50 to $2 per foot. In the oil regions of Pennsylvania the average price is about $1 per foot for the boring alone.

To the statements of Professor Carter it would be well to add that the presence of boulders, as in a glacial drift, very greatly increases the trouble and expense of well-boring, for the reason that they tend to shift their position during the drilling, thereby throwing the hole "out of true" and causing the tools to jam.

Logs of wood not unfrequently are encountered at great depths, and they always prove obstacles of considerable difficulty.

In Europe various deep bore-holes range in the following order:

	Feet.
Domnitz, near Weltin, Germany	3287
Probat-Jesar, Mecklenburg	3957
Sperenberg, near Zossen	4173
Unseburg, near Stassfurt	4242
Lieth-Elmshorn, Holstein	4390
Schladebach	5735
Rybuik, Upper Silesia	6571

"The Schladebach well was drilled under the supervision of the Prussian government, in search of coal. It appears that the total cost of drilling the well was $53,076, or at the rate of about $9.25 per foot of depth. The average daily rate of boring was 4.59 feet. The initial diameter of the hole is a little over 11 inches, and the least diameter in the lowest section is about 1.3 inches. Temperature observations which were made showed that at a depth of 5628 feet the temperature was 133.8° F.* Further work on this well has been abandoned."

* *Mechanical News*, December 15, 1892.

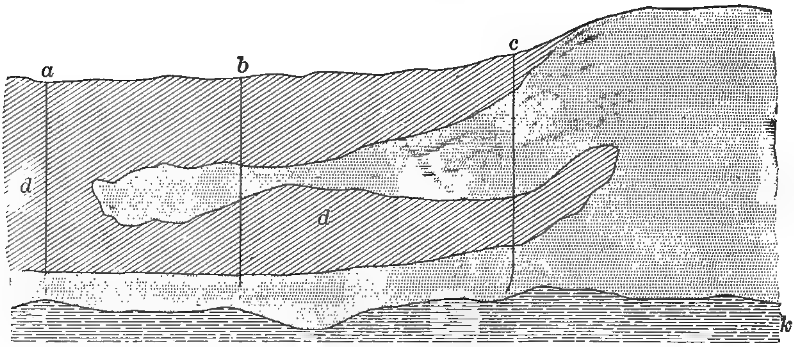
The Rybuik well is said to be the deepest in the world. A difficulty to contend with in so deep a boring lies in the great weight of the boring-tools, which in this instance reached 30,155 pounds. Ruptures were naturally frequent and finally caused stoppage of the work. The cost of the boring was about $2.86 per foot. The temperature observations showed $53\frac{1}{2}°$ F. at the surface and 157° F. at the bottom, a difference representing an increase of about 1° F. for every 63 feet.*

The expression "artesian" has been extended to include deep wells under all conditions, but without proper license, because the term originally came from the name of the French province where deep wells were first successfully established, and such wells were "flowing." It is therefore to "flowing wells" only that the expression "artesian" properly attaches. Wells of this class were first sunk, in Europe, at Lillers, in Artois, in 1126. In the Sahara and in China they have been known for many centuries. Whether, however, the well be a flowing one or one from which the water has to be raised by power, the conditions governing the storage of such water are essentially the same as have been already given when speaking of deep springs. An outcrop of a porous stratum in a rainy upland acts as the collecting area; this stratum is of moderate dip and is enclosed by other strata, impervious to water, lying above and below.

Unless the strata form a basin or pocket the water of the porous layer will find its natural outlet in spring form where the layer is cut transversely by erosion or fault; but should a well be sunk at some intermediate point the water will rise in the same, or overflow, to a degree dependent upon the head to which it is subjected; that is, to the elevation of the gathering-grounds above the well, and to the freedom with which

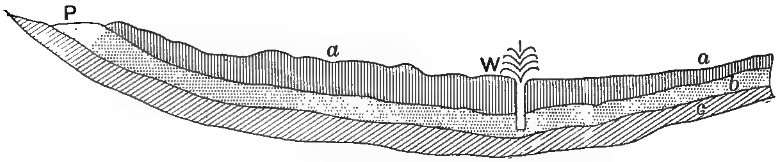
* See *Engineering News*, Dec. 31, 1896.

the water can flow down the porous stratum and escape through the outlets below.

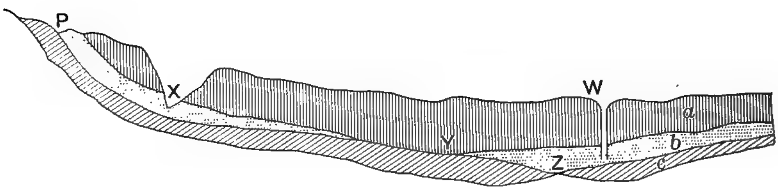


CONDITIONS OF WATER-BEARING STRATA IN RELATION TO OTHER FORMATIONS. (AFTER ROBERT HAY.)

a, well with one water-level ; *b* and *c*, wells with two water-levels ; *g*, water-bearing gravel; *k*, impervious shale.



CONDITION FAVORABLE FOR FLOWING WELL. (AFTER HAY.)



CONDITION UNFAVORABLE FOR FLOWING WELL. (AFTER HAY.)

It must be remembered in this connection that the expression "deep" refers to the non-local character of the water rather than to the depth of the hole required to tap the same. In fact "deep water" may lie very near the surface in some places.

It would be difficult to find an artesian field more deserving of study, or more interesting to the investigator, than the one

underlying the southeastern corner of the United States, and which is tapped by the wells of northern Florida, notably that of the Ponce de Leon at St. Augustine.*

No one has better knowledge of that interesting well than Mr. W. Kennish, who was in charge during its construction. The following data concerning the boring, together with the analysis of the water, given later, are partly taken from private correspondence with Mr. Kennish and partly from his letters to the *Engineering News:*

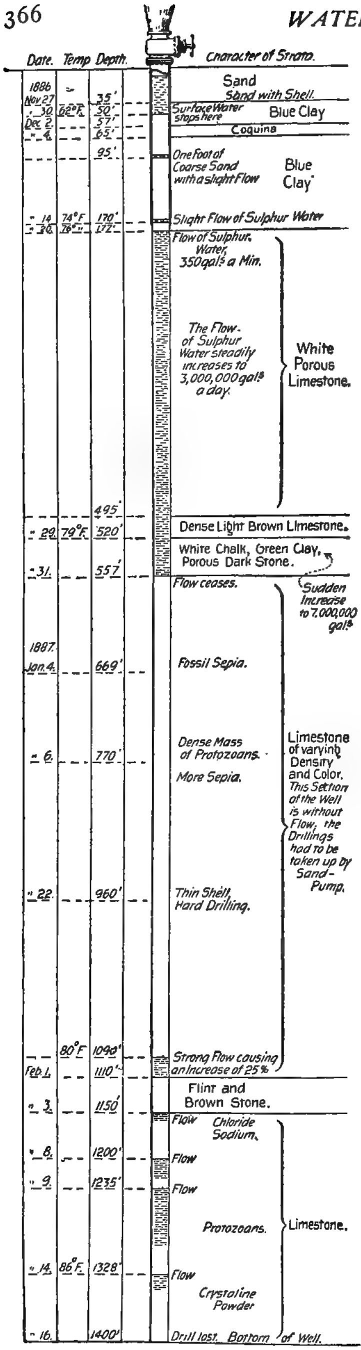
"The pressure was found to be 17 pounds to the inch, and the flow 10 millions of gallons in 24 hours.

"A turbine wheel fed by this flow maintained 120 incandescent lights at 16 candle-power, proving that the well was capable of supplying a force equal to 15 horse-power.

"Concerning the maintenance of the supply, we are possessed of information upon which to form a judgment. There are now in the town of St. Augustine and its immediate vicinity in the neighborhood of fifty artesian wells varying in diameter from 2 to 12 inches, and exactly the same force exists to-day as when the first well was driven, about ten years since. Another ground for believing that the supply of water is so abundant that it will prove equal to any possible draught upon it by artesian wells lies in the unvarying pressure indicated by the very sensitive gauge of the electrical apparatus operated by the 12-inch well, surrounded as it is by wells on all sides being used in constantly varying quantities. Again, the increase in the diameter of the wells has been attended by more than a proportionate flow.

"While the dynamo was being operated by the 12-inch well a 6-inch well in its vicinity was turned on and off suddenly to test the steadiness of the force, but the closest observation did not detect the slightest trembling of the gauge.

* See also the excellent reports on the deep wells of New Jersey in Report of State Geologist for 1897 and following years.



PONCE DE LEON ARTESIAN WELL,
ST. AUGUSTINE, FLORIDA.

"From these various sources of information we cannot escape from the conclusion that the water under pressure beneath St. Augustine and vicinity is practically boundless.

"The ratio of increase in temperature is very nearly 1° in every 50 feet. This increase was maintained until 86° was obtained at 1400 feet, where the well was stopped.

"Between 520 and 557 feet the rock changes from fossiliferous limestone to conglomerate of chalk, green clay, and a very porous dark fossil stone, largely composed of moulds of shells, the substance of which has been washed out.

"This stratum, of 37 feet in thickness, is doubtless cavernous, through which an enormous flow passes, possibly to find its partial escape in the great ocean spring, five miles seaward from Matanzas, and possibly, still further from the shore, and at greater depth, to swell the great ocean current —the Gulf Stream."

Such successive water-bearing strata as were encountered in the St. Augustine well are very frequently observed. Thus in a boring at Fort Worth, Texas,

at a depth of 900 feet a stream of water was struck flowing 170 gallons per minute, with a pressure of 15 pounds per square inch. At a depth of 1035 feet another lower stream was reached of 200 gallons per minute and pressure of 21 pounds per square inch. This second stream having been also cased off, further boring developed a flow at 1127 feet in depth of 245 gallons per minute, with a pressure of 29 pounds per square inch.*

One interesting feature of the deep wells of northern Florida and of the sea-springs off the coast is the very great distances the waters must flow in their subterranean passage from the uplands of the interior, for there is no land within a long distance of St. Augustine of sufficient elevation to produce the "head" observed at the wells.

Nearly akin to the Florida wells are those furnishing the public supply for Charleston, S. C., but the pressure and delivery from these latter are not so great.

There are three of these flowing wells at Charleston, all of about equal depth, and furnishing the following amounts of water daily:

$2\frac{11}{16}$-inch diameter........ .	200,000 gallons
$3\frac{1}{4}$ " "	300,000 "
$5\frac{1}{2}$ " "	1,250,000 "

They pass through the following strata:

Feet.		Feet.	
0 to 2	Mould	293 to 390	Calcareous marl, with nodules
2 to 8	Yellow sand	390 to 393	Arenaceous limestone
8 to 12	Sandy clay	393 to 454	Calcareous marl
12 to 17	White sand	454 to 466	Arenaceous limestone
17 to 50	Blue clay	466 to 475	Calcareous marl
50 to 61	Blue clay sands	475 to 476	White limestone
61 to 65	White sands	476 to 489	Calcareous marl
65 to 85	Sandy marl	489 to 540	Alumina magnesian marl
85 to 203 203 to 293	Argillaceous marl, with nodules	540 to 794	Marl

* Senate Doc. 41, 52d Congress, p. 106.

Feet.	
794 to 836	Micaceous marl, with iron pyrites
836 to 960	Marl with sandstone layers
960 to 998	Sand, considerable water
998 to 1000	Hard sandstone
1000 to 1215	Marl, sand, and clay
1215 to 1221	Sandstone, very hard
1221 to 1230	Marl, sand, and clay
1230 to 1310	Sandstone
1310 to 1345	Dark sand and clay
1345 to 1350	Broken shell and shell-rock
1350 to 1390	Blue clay, with hard layers
1390 to 1405	Green sand
1405 to 1533	Marl, some shell, and some iron pyrites
1533 to 1557	Hard sandstone
1557 to 1560	Sand, water-bearing
1560 to 1610	Argillaceous sand and sandstone
1610 to 1820	Blue clay and sand
1820 to 1845	Sand, with water
1845 to 1850	Sand-rock, hard
1850 to 1860	Loose white sand
1860 to 1862	Sandstone, hard
1862 to 1880	Loose sand, with water
1880 to 1900	Blue clay and sand
1900 to 1910	Sand
1910 to 1925	Argillaceous sandstone
1925 to 1970	Alternation of sand-beds 8 or 10 feet thick, and sandstone 2 to 5 feet thick between the beds
1970	Sandstone, not penetrated

The direct connection with the sea of the water-bearing layers which these wells tap is shown by the water in them rising and falling with the tide, and it is of special interest to note the fact that the daily fluctuations in the wells do not coincide in point of time with the tides at Charleston, a circumstance to be explained by the hypothesis of a very distant connection with the sea.*

A singular case, illustrating the danger that may possibly follow the tapping of water-bearing sand under pressure, is mentioned in "Abstracts of Papers," Institution of Civil Engineers:†

"The town of Schneidenmuehl, in which the well referred to is situated, lies in the province of Posen, near the west Prussian boundary. In the autumn of 1892 the sinking of the well was commenced, and in May of the next year had reached a depth of 238 feet. From 49 to 52 feet of the upper layers were comparatively firm; then a layer of sandy silt was struck,

* There was a famous temple of Melcarth at Gades, containing a mysterious spring which rose and fell inversely with the tide. (Bosworth Smith, "Carthage and the Carthaginians.")

† See also *Engineering News*, December 20, 1894.

having a thickness of 180 feet. A current of water was used during the boring operations as long as the upward pressure of the ground-water permitted. The tubes had a diameter of 4.72 inches to a depth of 82 feet, when they were reduced to 3.15 inches.

"On reaching a depth of 210 feet a strong current of muddy water issued from the tube. Sinking was continued, when at a depth of 236 feet the flow from the tube ceased; but a strong jet of water, amounting to 220 gallons per minute and containing 5 to 6 per cent of solid matters in suspension, issued through the ground at the side of the tube. The cause of the hydrostatic pressure which ejected the water with such force is sought for in the geological formation underlying the town of Schneidenmuehl. This town lies in the valley of the river Kuedow, an effiuent of the Netze, and is partially surrounded by hills composed of drift sand, which offer little obstacle to the percolation of any rain-water falling upon them. Upon this sand, however, lies an impervious deposit composed of the more or less clayey sediment left by the river, and this deposit appears to have resisted the pressure of the water until it was pierced during the sinking of the well.

"An endeavor was made to stop the flow of water by drawing the tubes, but this proved unsuccessful, because all solid matter which fell into the well from its sides was at once ejected with the water. Owing to the quantity of sand thrown out considerable subsidences of the surface took place, and the adjoining buildings were seriously damaged. Bags of sand and clay, stones, etc., were thrown into the well; but these were all swallowed up without staying the flow of water. An attempt was then made to dredge out a well or shaft round the tube, but after eight days' hard work a depth of only 2 feet was reached, owing to the quantity of sand driven up from below. It was next decided to drive down several tubes to the depth from which the water came, and this was done; but

several of the tubes sank and were lost, so that finally only one tube remained, the minimum diameter of which was 5.9 inches. On the 15th of June the ground sank suddenly to the extent of 4.26 feet, carrying with it part of the adjoining houses. After this the flow of water became less, and none reached the surface except through the tube. On the 21st of June tubes of gradually diminishing diameter were fixed upon the main tube, when it was found that the water rose to a height of 65.6 feet above the street-level. By means of taps at different levels the water was gradually cut off, and on the 22d of June it had altogether ceased to flow, and the danger to the town appeared to have been averted.

"On the 20th of September, however, the plug which closed the tube was removed, and the water again began to flow, sometimes containing as much as 20 per cent fine sand. The water forced its way upwards outside the tube, and finally the tube and the whole superstructure of the well sank. The method devised to close the well was to heap as rapidly as possible sufficient earth or sand upon the spot, so that the weight of the layer would counterbalance the upward thrust of the water. An area 69 feet in diameter was cleared, and the six tubes were carefully filled with fine sand. The earth and sand which had previously been brought to the spot were thrown in at the rate of 1.962 cubic yards per minute until a conical mound was formed 6.56 feet high and 69 feet in diameter at its base. This method proved successful, and the issue of water from the bore-hole has now ceased."

Flowing wells at times occur which are not due to hydrostatic pressure, but to the lifting of local water by gas-expansion. Such a case is reported by Professor Hay as occurring in southeastern Kansas.*

The same author also refers to "rock-pressure" as a cause

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* Senate Doc. 41, 52d Congress, p. 38.

ARTESIAN WELL AT WOONSOCKET, SOUTH DAKOTA.

Depth of well, 750 feet.
Height of stream above ground, 80 feet.
Diameter of well, 7 inches.
Pressure per square inch, 140 pounds.
Temperature of water, 63° F.
Discharge per 24 hours, 11,500,000 gallons.

of flowing wells of great depth. He claims that such wells tap sections of rock which are, together with the contained water, under enormous compressive strain, and the partial release of pressure in one direction causes the water to rise in the tube. This theory is combated by R. L. Jack, Government Geologist, Queensland.*

A phenomenon occasionally met with in deep, non-flowing wells is that of "breathing." Mr. J. T. Willard, of Kansas, has reported a very interesting instance of that kind in which close observation was kept of the entrance or exit of air, and the corresponding barometric readings. With a low barometer the well air took an outward direction, and the reverse condition followed increased atmospheric pressure. Mr. R. T. Smith, of Winona, Kan., "utilized such an air-current to blow a whistle which could be heard all over the town, warning the inhabitants of a possible storm." Of course the volume of air moving in such cases is far greater than what would be equal to the cubic contents of the well-tube, and it comes from a storage in porous or cavernous strata.

Attention is called by various writers—notably by Messrs. Todd and Swezey—to the liability of these "breathing wells" to freeze, owing to the sudden inflow of cold winter air from the outside. "The pumps not infrequently froze to the depth of 70 or 80 feet below the surface, and in one case ice had been found in a pump-cylinder 100 feet down, which was about 10 feet above the water."

Other things being equal, the ability of a well to furnish an abundant supply of water will depend upon the water-absorbing qualities of the rock in which the well is bored. The following values are given by Hill: †

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* Aust. Asso. Adv. Sci., 1895.

† Senate Doc. 41, 52d Congress.

CAPACITY OF ROCKS TO ABSORB WATER.

(Expressed in parts by weight of water absorbed by 100 parts of rock.)

Sandstone	4 to 29
Chalk	24.10
Coal shale	2.85
Basalt	0.83
Granite (fine-grained)	0.12
Granite (hornblende)	0.06

The author found the following values for the rocks of the State of New York: *

Diorite, Palisades	0.22
Granite, Peekskill	0.81
Granite, St. Lawrence	0.23
Gneiss, N. Y. City	0.19
Mica schist, N. Y. City	0.39
Hornblende schist, Antwerp	0.05
Red slate, Granville	0.00
Serpentine, Jefferson County	0.35
Talc, St. Lawrence County	0.43
Dolomite, St. Lawrence County	0.29
Potsdam sandstone, Potsdam	1.90
Chazy limestone, Chazy	0.13
Bird's-eye limestone, Watertown	0.07
Trenton limestone, Trenton Falls	0.04
Hudson River shale, Cohoes	0.97
Oneida conglomerate, Utica	0.09
Medina sandstone, Medina	2.49
Green shale, Rochester	0.27
Clinton limestone, Rochester	0.23
Niagara shale, Rochester	1.13
Encrinal limestone, Lockport	0.11

* Each specimen was weighed, soaked in water for forty-eight hours, rapidly wiped with a damp cloth, and again weighed.

Niagara limestone	0.63
Lower Pentamerous limestone, Schoharie	0.48
Oriskany sandstone, Oriskany Falls	1.44
Schoharie grit, Schoharie	0.32
Onondaga limestone, Jamesville	0.15
Blue flagstone, Kingston	0.39
Portage sandstone, Portageville	1.80
Conglomerate, Panama	3.73
Catskill sandstone, Catskill Mountains	0.90
Conglomerate, Catskill Mountains	0.55
Red shale, Catskill Mountains	0.72

Contrary to the belief of many people, deep-seated water is not inexhaustible. If the porous layers containing it be extensive, an immediately available supply of large volume, which is the accumulation perhaps of ages, may be counted upon; but should the daily drain be larger than the natural reinforcement, the delivery must surely shrink in quantity, and finally cease.

It is common knowledge that a great volume of water, some sixty-six million U. S. gallons, is drawn daily by the London water companies from deep wells in the chalk.*

The serious effect of extending and heavily pumping these deep chalk wells supplying a portion of London is thus pointed out in the *British Medical Journal* for February 28, 1891:

"For every two gallons of water collected within the Lee valley London is withdrawing three from its reservoir in that chalk basin, and this quite apart from the amount every day required by the resident population of that area. The result of such a process can only be a steady, if gradual, exhaustion of water from the chalk, and a progressive lowering of its plane of saturation; and, unfortunately, facts abundantly confirm this calculation, and prove that such a lowering of the deep-water

* London Water-supply, Shadwell, p. 48.

level is proceeding not merely in the valleys of the Colne and Lee, but in the main valley of the Thames itself as well; and this, moreover, to a degree which has already begun to excite the alarm of both agriculturists and manufacturers.

"Springs which were perennial and abundant thirty years ago have now run dry; the level of the water in deep wells has fallen more than 20 feet within less than as many years. Mills are being abandoned for lack of water-power, and rivers which once flowed regularly past ancient mansions, built to command a view of their bank-full streams, are now lost in swallow-holes, or flow only scantily, or for a few weeks in occasional years. In 1821 the water in a well in the east of London stood at Trinity high-water mark—22 feet above the present ordnance datum; in 1851 its average height was 43 feet below; and in 1881 it was 105 feet below ordnance datum, a lowering of 127 feet in sixty years, and indicating a fall in the plane of saturation in the chalk of more than 200 feet in the century. This depletion is not explicable on any theory of a diminished rainfall; for in this district the average of the last twenty years (during which the fall has taken place at an increasing rate) is nearly two inches above the average rainfall for the previous thirty years. The cause is to be found wholly and solely in the fact that water has been, and is being, increasingly drawn from the chalk basin in excess of its supply."

The "deep" supply for the town of Asbury Park, N. J., is quite typical of the low-lying waters of that coast, and is, moreover, an instance of the successful treatment of a water so highly ferruginous as to be unusable in the raw state.

The wells are ten inches in diameter and a little over one thousand feet deep and furnish a water containing 9.12 parts of iron per million. An "air-lift" is used to raise the water, which reaches the surface very red and roilly from suspended oxide of iron. After removal of this oxide by simple filtration

through sand an excellent water is obtained, clear and iron-free. The air is forced in through a one-inch pipe, at a depth of about two hundred feet and under a pressure of ninety to one hundred pounds. No clogging of the piping has been experienced.

It is right to say here that although in cases like that of Asbury Park, where oxidation of contained iron is demanded, the air-lift is suited to the existing conditions, yet the fact should always be considered that such a device for the purpose of simply raising water is of very doubtful economy, except where the lift is a small one.*

Deep water must not be expected in every locality. There is a widespread notion that every deep boring is sure to strike water in goodly quantity, if carried to sufficient depth, irrespective of any surface conditions whatever. The writer has been called to pass judgment upon the advisability of trying for an artesian supply for a settlement on the top of a mountain some three thousand feet high, and that, too, a mountain of erosion, with horizontal strata. Shallow borings, of only thirty to forty feet in depth, had furnished a limited quantity of water in the same general locality, and hence the proposition to increase the supply by the means above stated. The water obtained from the shallow wells was, of course, derived from the very local rainfall of the mountain-top, and was no indication whatever of a further deep supply, although the parties interested were of the opinion that water could be induced to run up-hill, owing to some occult "artesian" conditions.

Water from deep sources has, commonly, characteristics of its own, distinguishing it from the ground-water of the neighborhood. One of the most easily recognized of these is high

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* See *Engineering News*, April 22, 1897.

temperature. Albertus Magnus was the first to hold that low-lying waters are warmed by the native internal heat of the globe.

Aristotle believed the high temperature of such water to be due to solar heat which penetrated the crust of the earth and accumulated in the interior as at the focus of a lens.

An excellent illustration of the gradual increase in temperature with depth of boring has already been given in data concerning the Ponce de Leon well.

Another peculiarity of deep water is the small quantity of dissolved oxygen it usually contains. This is by no means due to the pressure to which it may be subjected, for increase of pressure favors the solution of gases, but is rather owing to the abundant opportunity for removal of oxygen by contact with such substances as organic matter, and compounds of iron and manganese, presented during the long underground journey of the water from its point of collection.

The water of the Grenelle well at Paris, which flows from a depth of 548 metres (about 1780 feet), contains no oxygen whatever.

Richardson finds that, as water at normal temperature and pressure absorbs .0245 of its volume of air, at a depth of 1380 feet it would absorb its own volume of air, measured at atmospheric pressure.*

In point of composition the waters of deep wells are almost always highly mineralized, as would be expected in consideration of the items of long time, long distance of flow, high pressure, and elevated temperature. Sometimes the materials contained render the water unfit for use, even for boiler purposes, but more commonly the supply is such as to be considered a great boon to the fortunate possessor.

Although manifestly foreign to the present writing, it may

* *Chem. News*, lxvii. 99.

be interesting to insert here the analysis of water from "Old Faithful" Geyser, which may be taken as typical of such waters from the Yellowstone Park.*

NH_4Cl	trace	
$LiCl$	34	per million
$NaCl$	639.3	" "
KCl	47.8	" "
$CsCl$	trace	
$RbCl$	trace	
Na_2SO_4	27	" "
KBr	5.1	" "
$Na_2B_4O_7$	21.3	" "
$NaAsO_2$	2.7	" "
Na_2CO_3	208.8	" "
Na_2SiO_3	27.9	" "
$MgCO_3$	2.1	" "
$CaCO_3$	3.8	" "
$FeCO_3$	trace	
$MnCO_3$	trace	
Al_2O_3	1.7	" "
SiO_2	369.1	" "
H_2S	0.2	" "
	1390.8	per million

Mr. Kennish furnishes the following analysis of the water from the Ponce de Leon well already spoken of. The water on issuing from the well has a strong smell of sulphuretted hydrogen (a quality also observed in the water of the Matanzas sea-spring), but all odor leaves it after standing a short time.

Suspended matter	1.6	per million
Silica	28.0	" "
Alumina	1.2	" "

* Gooch and Whitfield, Bul. 47, U. S. Geol. Sur.

Sodium chloride	1957.7	per million
Potassium chloride	47.5	" "
Magnesium chloride	353.4	" "
Calcium sulphate	470.9	" "
Strontium sulphate	18.6	" "
Magnesium sulphate	none	
Calcium bicarbonate	149.9	" "
Magnesium bicarbonate	162.1	" "
	3190.9	per million

A somewhat curious instance of the change that may come in the composition of a deep-well water from attempts to increase the flow by deeper boring was brought under the author's observation a few years ago. At a depth of 800 feet a valuable "saline" mineral water was obtained. With a view to increase the flow the owners sank the well to 1406 feet, when the water suddenly changed to one of "alkaline carbonate" character, heavily charged with marsh-gas and sulphuretted hydrogen.

Some years ago a small sample of brown water was sent to this laboratory by the gas company of Mobile, Ala. It came from an artesian well 600 feet deep, bored near the Gulf coast. A very simple and partial examination was made of it to determine its fitness for boiler use. It was decidedly alkaline from the presence of sodium carbonate, contained considerable salt, and in color was of a dark coffee-brown. It is to be regretted that circumstances did not favor a complete analysis of so interesting and unusual an artesian water. However, the gap has been filled by Professor Reuben Haines, who recently reported a "remarkable artesian-well water" from southern Alabama.* The description of the water, and the depth of the well (685 feet), combined with the location,

* *J. Fk. Inst.*, January, 1894.

ONE OF THE GROUP OF ARTESIAN WELLS SUPPLYING THE CITY OF JACKSONVILLE, FLORIDA.

The water rises ten feet above the surface of the ground.

lead to the conviction that the water was practically the same as the one examined by the writer some years ago.

The analysis and comments are best given in Professor Haines' own words:

"Color (observed in tube two feet long)—very dark coffee-brown.

"Odor (heated to nearly 100° C.)—unpleasant, odor of damp rotten wood.

"Taste (warm)—disagreeable, stale, brackish alkaline with organic flavor.

"Transparency—almost clear, a small amount of whitish sediment.

Free ammonia	6.900 per million
Albuminoid ammonia	0.740 " "
Oxygen consumed (Kubel)	10.892 " "
Nitrogen in nitrates	0.40 " "
Chlorine	998.0 " "
Total solid residue (dried at 120° C.)	2060.0 " "

"The mineral ingredients existed in the following combinations:

Potassium sulphate	2.2 per million
Potassium chloride	44.0 " "
Sodium chloride	1611.9 " "
Sodium carbonate	293.3 " "
Calcium carbonate	26.8 " "
Magnesium carbonate	13.4 " "
Silica, iron oxide, and alumina	8.5 " "
	2000.1 per million

"The more remarkable features of this artesian-well water which are here to be noted are the very high color, approximating that of water from pools in bogs and swamps, and the enormous amounts of ammonia and of organic matter. Deep-

well and artesian waters are usually colorless and particularly free from organic matter, on account of the vast amount of filtration to which they are generally subjected. It does not seem probable that so excessive an amount of ammonia as occurs in the Alabama well can be referred to decomposition of the vegetable substance alone, but that a portion of it, at least, must be caused by decomposition of the organic remains of fish and other marine animals, which have been, perhaps, partially preserved from decay through the antiseptic properties of peat. A quantity of bones and shells mingled with sand is stated to have been thrown up by this well.

"The excessive amount of sodium chloride in this well-water may be attributed to the probable existence of saliferous beds somewhere in the vicinity. From the results of analysis it is manifest that the water has no direct connection with the sea, for its mineral composition is totally unlike that of sea-water. The pressure of the water at the mouth of the well is of itself sufficient evidence that the water has an altogether different origin."

Water of high color and of general swampy character is to be found in the deep wells in the vicinity of New Orleans, and is also reported in Colorado.* Only one explanation is apparent for all these cases, and that is that the water coming from its distant gathering-ground is constrained, for a portion of its underground course, to pass through deep-lying deposits rich in organic remains.

As to what kind of rocks yield hard water and what kind furnish soft, we have but to consider the chemical and physical structure of the rock in question, and then, from the solubility data, a very fair judgment can be arrived at. Professor Carter has summed up this question very aptly.† He says:

* *J. Am. Water-works Asso.*, 1897, p. 137.

† *J. Fk. Inst.*, September, 1893.

"Water that passes through calcareous or magnesium rocks of great thickness will probably be hard, while water that passes through rocks composed of silica, alumina, iron, potash, or soda will probably be soft. The great deposits of limestone, marble, gypsum, and other calcareous rocks, as well as the magnesian rocks, such as dolmoite, chlorite, and talcose schists, would then yield hard water. The granites, gneisses, and many sandstones and slates would furnish soft water. This, in the main, is true, although there are some exceptions which local conditions modify. Some sandstones will yield soft water, while other sandstones furnish hard water; it depends mainly upon the cement which binds the grains together. If the cementing material be carbonate of lime or sulphate of lime, the water will probably be hard, especially if the well be of great depth and the water be long in contact with the rocks. If, on the other hand, the cementing material be feldspar, such as orthoclase or albite (not labradorite), or even gelatinous silica, the water will probably be soft.

"In England many determinations of the hardness of spring and artesian waters from different geological formations have been made; so that it can be safely predicted what kind of water an artesian well will yield when it is drilled in the Devonian, in the Silurian limestone, in the new red sandstone, or in the chalk.

DEEP ARTESIAN-WELL WATER (ENGLAND).

	Hardness.	
Water from Devonian sandstone	17°	Hard waters.
Water from magnesian limestone	43°	
Water from new red sandstone	17°	
Water from chalk	27°	

Water from granite and gneiss, soft.
Water from Silurian sandstones, slate, and shales, soft.
Water from millstone grit, soft.

"Water which flows through calcareous channels is hard, while that which flows through silicious rocks is soft."

As has been shown, deep water may at times be too highly mineralized, or even too "peaty," for potable use, but such impurity is not all that may be present on occasion.*

Even a deep well, especially if not a true flowing artesian, is not always exempt from local infiltrations of contaminating character. This is especially seen in the deep borings within the limits of the city of New York. The character and vertical position of the rock strata underlying the metropolis are such as to permit surface drainage to reach to very considerable depths. The writer condemned a deep-well water from Erie, Pa., upon the following analysis:

Free ammonia	2.025
Albuminoid ammonia	none
Chlorine	69
Nitrogen as nitrates	.025
Nitrogen as nitrites	none
"Required oxygen"	.85
Total solids	487
Phosphates	strong traces

Further information showed the well to have been bored within city limits, through a friable rock, and "within 75 feet of the nearest privy-vault."

Adverse report was also made upon another well, which had been very carefully bored through rock (shale) for 200 feet. Within 50 feet of the well was a large privy-vault. Sixty-five pounds of salt, dissolved in three barrels of water, were thrown into the vault, and the water of the well was watched for increased chlorine, with the following results:

* Sworn statements have been made to the effect that numerous small fish were found in water issuing from deep artesian wells in Aberdeen, S. D., 1891, six hundred miles from any known surface source of such fish. (Senate Doc. 41, 52d Congress, part 2, p. 86.)

Before "salting"	58	parts chlorine per million
After 15 hours' pumping	64.25	" " " "
" 36 " "	64.37	" " " "

Other but hardly necessary instances could be given of contamination from adjacent elevator-shafts, gas-works, and the like.

The following point was brought out by Mr. Fanning during discussion of a paper before the American Water-works Association. Mr. Fanning said:

"While recently making an examination of the sources of water-supply for a city of New Jersey, located near a larger city, I gathered the data of the wells in the vicinity and over the southwestern part of the State with a view of learning the amount and direction of dip of the successive strata from the surface down, and of estimating the probable water-supply from the water-bearing sand strata available for a city water-supply. In that city the question of a well-supply had been earnestly discussed and was favorably considered. After plotting, in a diagram, the information showing the inclination and direction of the strata, the evidence seemed clear that the outcrop of the strata and the watershed which would supply the water to wells in that city were in the neighboring city. It seemed to me unwise and unsafe for them to depend for their own water-supply upon the water that falls upon the surface in and about the neighboring city.

"This case illustrates the frequent necessity of tracing an underground water-supply to its surface source and watershed, that there may be assurance that it is unobjectionable and clean, for if the source be unclean the filtration through the sand stratum will not protect it indefinitely."

Finally, a word concerning the probability of finding bacteria in deep wells. Waters from such sources are not to

be rated as "uniformly sterile." Leaving out of consideration such instances as wells which permit the direct entrance of surface drainage, there are yet many deep waters showing abundance of bacterial life; but, fortunately, the chances of encountering therein germs of objectionable character are reduced to a minimum. Prof. Sedgwick has lately reported his findings upon this question:

"From our results we are forced to the conclusion that ground-waters, even the waters of deep wells, may not be by any means as free from bacteria as has been hitherto supposed.

"It is plain that water absolutely free from bacteria is not ordinarily obtained from even deep wells, and that many deep wells contain as numerous bacteria as are found in many surface-waters."

The bacteria present in these waters are, however, "remarkable not only for slow growth, but also for the absence of liquefying colonies, and, in many cases, for the abundance of chromogenic varieties. These facts are especially important as indicating the total absence of contamination by ordinary surface-water, and, as far as they go, they strengthen the confidence with which well-protected ground-waters may be regarded as sources of public water-supplies." *

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* Sedgwick, Rep. Mass. Board of Health, 1894.

CHAPTER X.

QUANTITY OF PER CAPITA DAILY SUPPLY.

THE following table is from a more complete one issued by the *Engineering News*, April 18, 1901:

PER CAPITA WATER CONSUMPTION IN THE FIFTY LARGEST CITIES OF THE UNITED STATES IN 1890 AND IN 1900, ARRANGED IN ORDER OF POPULATION.*

Cities.	Per Capita Consumption, Gallons.		Increase or Decrease, Consumption, in 10 Years. Gallons
	1890.	1900.	
1. New York †	79	116	+ 37
2. Chicago	140	190	+ 50
3. Philadelphia	132	229	+ 97
4. Brooklyn †	72	....	....
5. St. Louis	72	159	+ 87
6. Boston	80	143	+ 63
7. Baltimore	94	97	+ 3
8. San Francisco	61	73	+ 12
9. Cincinnati	112	121	+ 7
10. Cleveland	103	159	+ 56
11. Buffalo	186	233	+ 47
12. New Orleans	37‡	48‡	+ 11
13. Pittsburg	144	231	+ 87
14. Washington	158	185	+ 27
15. Detroit	161	146	− 15
16. Milwaukee	110	80	− 30
17. Newark	76	94	+ 18
18. Minneapolis	75	93	+ 18
19. Jersey City	97	160	+ 63
20. Louisville	74	100	+ 26
21. Omaha	94	176	+ 82
22. Rochester	66	83	+ 17
23. St. Paul	60	67	+ 7

* The classification is by the census of 1890, so as to include all the cities in the earlier grouping.

† New York and Brooklyn consolidated since 1890.

‡ Only a small part of the population supplied.

PER CAPITA WATER CONSUPMTION IN PRINCIPAL CITIES.

Cities.	Per Capita Consumption, Gallons. 1890.	1900.	Increase or Decrease, Consumption, in 10 Years, Gallons.
24. Kansas City	71	62	− 9
25. Providence	48	54	+ 6
26. Denver	....	300	....
27. Indianapolis	71	79	+ 8
28. Allegheny	238	....	....
29. Albany	....	191	....
30. Columbus	78	230	+ 152
31. Syracuse	68	102	+ 34
32. Worcester	59	70	+ 11
33. Toledo	72	119	+ 37
34. Richmond	167	100	− 67
35. New Haven	135	150	+ 15
36. Paterson	128	129	+ 1
37. Lowell	66	85	+ 19
38. Nashville	146	140	− 6
39. Scranton	....	....	....
40. Fall River	29	36	+ 7
41. Cambridge	64	79	+ 15
42. Atlanta	36	84	+ 48
43. Memphis	124	125	+ 1
44. Wilmington	113	90	− 23
45. Dayton	47	62	+ 15
46. Troy	125	183	+ 58
47. Grand Rapids	....	156	....
48. Reading	75	92	+ 17
49. Camden	131	280	+ 149
50. Trenton	62	99	+ 37

A very different showing in the matter of per capita consumption is made by the English cities:

WATER-SUPPLY PER CAPITA OF THIRTY-SIX ENGLISH PROVINCIAL CITIES.

(London County Council Report.)

City.	Year.	Population Supplied.	Average Daily Supply, U.S. Gals., per capita.
Barrow	1897	65,300	42
Birkenhead	1897	102,978	31
Birmingham	1896	680,140	28
Bolton	1897	250 000	26
Brighton	1897	165,000	43
Bradford	1897	436,260	31
Burnley	1897	104,450	26
Bury	1897	157,500	29
Cardiff	1897	170,000	29
Coventry	1897	60,100	28
Croydon	1897	96,300	35

City.	Year.	Population Supplied.	Average Daily Supply, U.S. Gals., per capita.
Derby	1897	111,470	27
Gloucester	1897	43,000	21
Halifax	1897	217,000	24
Huddersfield	1897	146,930	30
Hull	1896	224,064	49
Ipswich	1897	60,000	21
Leeds	1896	420,000	43
Leicester	1896	220,005	22
Lincoln	1897	51,961	28
Liverpool	1896	790,000	34
Manchester	1897	849,093	40
Middlesborough	1896	187,331	61
Newport	1897	72,362	27
Northampton	1897	70,000	23
Nottingham	1897	272,781	24
Oxford	1897	53,000	30
Plymouth	1897	98,575	59
Reading	1897	71,558	42
St. Helens	1897	85,000	49
Salford	1897	117,081	26
Sheffield	1897	415,000	21
Southampton	1897	76,430	45
Swansea	1897	100,000	35
Wigan	1897	60,000	20
Worcester	1897	45,000	43
Average	....	....	33

WATER-SUPPLY PER CAPITA IN GERMAN CITIES.

(After Brackett.)

Place.	Population.	Daily Consumption, U. S. Gals.	Place.	Population.	Daily Consumption, U. S. Gals.
Altona	156,500	26.07	Hanover	189,976	18.40
Barmen	118,500	33.59	Halle	120,000	21.94
Basel	74,500	34.78	Karlsruhe	74,200	28.14
Berlin	1,606,424	16.37	Kiel	72,000	20.18
Bonn	52,000	24.94	Königsberg	162,000	16.87
Breslau	335,000	21.71	Magdeburg	198,000	25.24
Chemnitz	139,374	11.50	Munich	298,000	34.00
Cologne	255,000	45.22	Nuremberg	145,000	17.41
Crefeld	105,712	18.52	Posen	70,000	13.33
Danzig	107,085	26.70	Stettin	118,000	31.54
Dresden	280,200	21.54	Stuttgart	139,200	21.34
Düsseldorf	155,900	22.10	Wiesbaden	66,000	20.74
Elberfeld	137,000	29.92	Würzburg	61,032	35.50
Frankfort	186,000	36.26	Zurich	96,650	56.71
Freiburg, B.	48,200	41.46			
Hamburg	583,700	58.00	Average	....	27.69

The average daily per capita supply for the cities and towns of New Jersey * for 1893 was 99 gallons.

The nine large conduits of Rome at the time of Nero delivered 173,000,000 gallons daily. Afterwards the increased supply furnished 312,000,000 gallons daily, or over 300 gallons per capita per day.†

Upon glancing over such data as have been given for cities of the United States, and bearing in mind how often the water furnished our towns is inferior in character, one is impressed with the thought that we Americans are much more concerned about the quantity of the supply than about its quality.

There is no question but that our allowance is unreasonably large. Fifty gallons is considered a generous amount per individual in Europe, but it would be deemed quite a small quantity here in America.

If we had but an increased cleanliness to show for our great use of water, there would be a measure of compensation for the additional cost, but the writer confesses to an inability to detect wherein our American cities are superior to those of Europe in this particular.

Mr. D. Brackett makes the following analysis of the daily uses of water:

"The quantity needed for domestic use is not more than 30 gallons per inhabitant, and in communities where the number of water-fixtures is small in proportion to the population supplied a smaller quantity will answer all requirements. For business, mechanical, and manufacturing uses the amount per capita will differ very largely in different cities, and for various reasons. It is not probable, however, that the actual requirement exceeds 40 gallons per capita in any of our large cities."

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* Report of State Geologist.

† Senate Doc. 41, 52d Congress, part 1, p. 431. For estimates of Forbes and Clemens Herschel see p. 10.

In an address before the Board of Aldermen in Brooklyn, N. Y. (Feb. 11, 1897), Mr. Samuel McElroy considered the following analysis for domestic use a reasonable allotment per capita:

For drinking and cooking....	1 gallon
Laundry....	6 gallons
Bathing.	7 "
Water-closets...........	6 "
Flushings and waste.......	5 "

—a total of 25 gallons, beyond which the draught is waste, in his opinion.

Analysis of the sundry items included under the general head of "Water for Public Purposes": *

	U. S. Gallons per Capita per Day.
Public buildings, schools, and hospitals	2.30
Street-sprinkling.	1.00
Flushing sewers and public urinals	.10
Ornamental and drinking fountains. .	.25
Fires...	.10
Total for public purposes	3.75

"Probably 4 or 5 gallons per capita should cover all requirements for public purposes."

The simple, useless waste of water in our cities is something enormous. In Chicago, Cleveland, Philadelphia, and Detroit the probable waste is fixed at about 50 per cent, while in Buffalo the enormous figure of 70 per cent is given by the city engineer. The waste for New York City is given as "at least 40 per cent" by the *Water and Gas Review*.

That the great bulk of this waste could be saved by meter measurement is an already demonstrated fact, and the fixing

* *J. N. E. Water-works Asso.*, xi. 71.

of a minimum daily allowance of water, for which the consumer would have to pay, whether he used it or not, would remove the objections that might be raised to meters upon sanitary grounds. The author has corresponded with city health officers in various parts of the country, with a view of determining what, if any, is the effect of the meter system upon public health, arising from an attempt on the part of the poorer classes to economize in the use of water. The reply from Providence, R. I., is quite typical: "I do not find that it diminishes the proper use of water in the slightest degree. Its only tendency is to diminish waste. There is in my opinon no objection, from a sanitary point of view, to the use of meters."

How great the useless waste of water may be is well shown by Mr. F. Crosby,* who has prepared a somewhat lengthy table of daily per capita supplies before and after such waste was stopped. Taking an average of twenty of the numerous cases quoted, the per capita figures stand:

Before repairs were made.........	1572 gallons
After " " "	281 "

The experience of Mr. Dexter Brackett leads him to be "of the opinion that it is not practicable to reduce the waste below 15 gallons per capita in our large cities, and that it cannot be maintained at that figure except by the universal use of water-meters, aided by Deacon meters or some similar device for detecting leaks in the street-mains. In cities where water-meters are not generally used the quantity wasted will be from 20 to 100 gallons per capita, as the inspection of mains and house-fixtures is more or less rigid."

The following-named cities are fair illustrations as to prevention of waste as shown by the use or absence of a meter system:

* *Jour. Am. Water-works Asso.*, 1895, p. 90.

"Atlanta, 89.6 per cent, metered, 36 gallons per capita.

"Fall River, 74.6 per cent, metered, 29 gallons per capita.

"Allegheny City, no meters, 238 gallons per capita.

"Buffalo, $\frac{2}{10}$ per cent, metered, 186 gallons per capita.

"Richmond, 1.4 per cent, metered, 167 gallons per capita.

"Detroit, 2.1 per cent, metered, 161 gallons per capita.

"Halifax, with one half the population of Fall River, has three times the per capita consumption." *

A spirit of prophecy must certainly enter the engineer who would accurately determine the future population of a city in order to provide sufficiently for its water-supply.

In a paper read before Section I, American Association for the Advancement of Science, at Springfield, Mass., September 3, 1895, Mr. E. L. Corthell dealt exhaustively with the growth of population of great cities and graphically illustrated the several densities and curves of increase.

"Recapitulating the statements in regard to ratio of increase at present in the several cities noted, the following summary is given:

PRESENT PERCENTAGE OF INCREASE PER DECADE.

London	10.4
Greater London	18.0
New York	33.3
Paris	10.0
" average last three decades	12.7
Chicago	106.5
Berlin	37.0
Philadelphia	25.0
St. Petersburg	15.0

"Even with the problematic conditions disturbing the future, there is sufficient ground on which to rest a prediction

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* *Water and Gas Review.*

of population, which the author has the temerity to make, as follows:

City.	Est. pop. in 1900.	Est. pop. in 1910.	Est. pop. in 1920.
Greater London. . . .	6,496,000	7,470,400	8,516,256
London	4,599,800	4,967,784	5,315,528
New York	3,900,000	4,953,000	6,191,250
Paris.	2,697,300	2,967,030	3,234,063
Berlin.	2,101,400	2,731,820	3,496,729
Chicago.	2,400,000	4,560,000	8,208,000
Philadelphia.	1,414,500	1,697,400	2,002,932
St. Petersburg.	1,185,600	1,339,728	1,500,495

As supplementary to what has been said it may be interesting to note the rates charged for water in eleven cities that have adopted the general meter system: *

	Rate.	Per Gal.	Minimum.
San Francisco, Cal. . . .	$21\frac{1}{3}$ to 40 c.	1000	$19.00
Providence, R. I. . .	15 " 20	"	10.00
Fall River, Mass. . . .	10 " 28	"	16.00
Hoboken, N. J.	$15\frac{2}{3}$ " $23\frac{1}{3}$	"	13.00
Yonkers, N. Y.	$5\frac{1}{3}$ " $26\frac{4}{5}$	"	13.00
Pawtucket, R. I. . . .	6 " 30	"	10.00
Newton, Mass.	12 " 35	"	10.00
Woonsocket, R. I. . .	10 " 30	"	10.00
Bayonne, N. Y	$13\frac{1}{2}$ " $23\frac{1}{3}$	"	. . . . .
Fitchburg, Mass.	5 " 35	"	. . . . .
Madison, Wis.	$6\frac{2}{3}$ " $26\frac{2}{3}$	"	5.00

A city ordinance of Brooklyn, N. Y., reads as follows:

"All water used for manufacturing purposes shall be charged for at the rate of one cent per one hundred gallons, or seven and one half cents per one hundred cubic feet, meter measurement. All water furnished and used for other purposes shall be charged and paid for at a rate of one and one half

* *Water and Gas Review.*

cents per hundred gallons, or eleven and one quarter cents per hundred cubic feet, meter measurement, provided, however, that in cases where an annual supply of water for a given purpose exceeds in cost the sum of one thousand dollars, meter measurement, such supply of water shall be furnished and paid for at the rate charged for manufacturing purposes.''

In Paris the spring-water supply is charged for at the rate of 35 centimes (7 cents) per cubic metre (264 U. S. gallons), with special reduction for the small houses of working men.

CHAPTER XI.

ACTION OF WATER UPON METALS: TANKS, PIPES, CONDUITS, BOILERS, ETC.

Lead.—Max Müller finds that the action of soft water on lead depends upon the relative amounts of oxygen and carbon dioxide present in solution. Distilled water free from carbon dioxide, but containing oxygen, hardly acts upon lead, and water containing carbon dioxide, but no oxygen, is also without action; yet waters containing a fixed amount of dissolved oxygen and varying amounts of carbon dioxide were found to act upon lead with an energy which increased directly as the amount of carbon dioxide present, up to a certain limit, after passing which the addition of more carbon dioxide diminished the action upon the lead and finally stopped it altogether.*

A full investigation was made by the Massachusetts Board of Health,† but no very decisive results are recorded. In a general way it may be said that, when experimenting with distilled water, dissolved oxygen greatly increases the action of the water upon lead, and that such action is further increased by the addition of ammonia or potassium nitrate, and it is greatly decreased by the presence of common salt, calcium carbonate, sodium silicate, "total solids," or organic matter. Carbon dioxide also increases the action.

The recent outbreak of lead-poisoning at Lowell, Mass.,

* *J. Chem. Soc.*, liv. 225.

† See Report of Mass. State Board of Health, 1898, p. 541.

has been traced to the solvent action of a well-water which was rather heavily charged with carbon dioxide. The water was found upon analysis to contain 230 parts of lead per million, an amount greatly in excess of the danger limit (0.5 part) as fixed by most authorities.

A. H. Allen finds by experiment that distilled water, acting overnight on bright lead, will contain lead carbonate in amount equal to 5.83 grains per U. S. gallon.*

Sulphuric acid, even in very small quantity, will, contrary to former opinion, increase the action of ordinary (not distilled) water on lead. Allen believes † the leading cause of the action of potable waters on lead to be the presence of a trace of some free acid.

Mr. Scattery, of England, has made some investigations relative to the influence of peaty material in causing an acid reaction in water and a consequent action upon lead. The plumbo-solvency of a troublesome water of this class in use at Wakefield, England, has been entirely removed by the use of carbonate of soda.‡

Referring to the action upon lead by peaty waters of acid reaction, the acidity being due to carbon dioxide and organic acids, Achroyd § says that he has never known plumbism to occur when the acidity of the water (using phenolphthalein as an indicator) was under the equivalent of 5 parts of sulphuric acid per million. He proposes this figure as a limiting standard of acidity for potable waters.

The acidity of sixty-one waters, which had never produced plumbism, varied from 2 to 4.1 parts per million with an average of 2.7.

A paper by Dr. Thompson before the British Medical

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* 100 parts per million.

† *Chem. News*, xlvi. 145.

‡ This treatment was undertaken upon the advice of Dr. Percy Frankland. See also his valuable article in *J. Soc. Chem. Ind.* for April, 1889.

§ *Chem. News*, lxxxii. 162.

Association in 1890 stated that Sheffield had a double supply of water: a high-level supply gathered from a damp peaty ground and delivered in an open conduit; and a second one, uncontaminated with vegetable material, and which flowed in a closed conduit. The former of these waters acted on lead pipe, and the latter did not. Many persons had died in Yorkshire from lead poisoning.*

The medical officer of health for Eccleshill, England, reports that the water-supply of the district contains lead to the average quantity of $\frac{1}{6}$ grain per imperial gallon.† Iron pipe is being substituted for all new services in the district.‡

That all peaty waters act on lead must not be inferred, as some very brown ones, notably from New Jersey, are without such action.

In a general way it may be said that soft waters attack, and hard waters protect, lead, but this rule is not without numerous exceptions, and one interesting exception is the fact that permanently hard water tends to attack the metal rather than to protect it. Waters of acid reaction take lead into solution, while those of neutral or alkaline character hold the basic hydrate or basic carbonate in suspension. As the latter class of waters often attack lead quite vigorously, the quantity of lead actually imbibed with an unfiltered water of this class may be considerably larger than in the case of a water where the lead is in solution.

There is often some question as to what produces the acidity of a particular water, but one eminent investigator believes that nitric acid is very commonly the cause. Certain it is that nitrates are ordinarily present in waters which attack lead.

Instances are on record of lead pipes having been in use

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* Report Surg.-Gen. U. S. Navy, 1890.

† 2.38 parts per million.

‡ *Chem. News*, lxx. 222.

during many years without having been acted upon by the water passing through them. Thus Fischer cites a case where the pipes had served over 200 years without action. An interior incrustation on a lead pipe which had been in use for conveying water at Andernach during a period of 300 years was found to consist of:

PbO	73.962
BiO_3	0.453
CdO	0.120
CuO	0.323
Fe_2O_3	1.552
Al_2O_3	1.035
CaO	1.095
MgO	0.283
P_2O_5	8.446
CO_2	1.110
Cl	1.254
Organic matter	0.388
SiO_2 and clay	4.399
Water	6.141
	100.561

The organic matter was said to have been caused by eels which had been formerly employed to clear the pipe from material which had clogged it.*

A very marked difference commonly exists between the action of the same water upon new, bright lead and upon that which is dull from exposure, i.e., "old lead."

Thus the writer found the following amounts of the metal (partly dissolved and partly suspended) in city rain-water which had been stored three and a half months in contact with lead surfaces of the above description.

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* *J. Chem. Soc.*, xxxviii. 198.

Old lead............	3.65	parts per million
New lead.	58.10	" " "

The important lesson derived from this is that lead-lined tanks for storage of rain-water, such as are often seen in the country, may grossly contaminate the water, especially while new, by diffusing throughout their contents the solid lead compounds formed by the action of the water. This form of contamination may be much greater than that arising from the lead actually in solution; but either form is bad, and if lead cisterns or storage-tanks be deemed necessary they should always be carefully painted on the inside with a good carbon (non-metallic) paint, and should be frequently inspected.

In this connection may be mentioned the danger of having a suction-pipe of unprotected lead leading to the bottom of the domestic well or the cement-lined cistern.

As already said, all waters do not act upon lead, and some very quickly form upon the metal a permanent protective coating; but there is so much conflicting evidence upon the question that, in order to decide in which class to place any given water, it is much better to resort to direct experiment, and permit two samples of the water to stand in contact with bright and with dull metal and afterwards estimate the lead in each sample, rather than to attempt to theorize upon the basis of the composition of the water.

Carbonate of calcium is very efficient in protecting lead from attack.

Crookes, Odling, and Tidy have shown also the great protecting power of calcium silicate, and their belief is that water becomes lead-proof when the contained silica amounts to about 7 parts per million.*

Where circumstances permit, an excellent method of checking the lead-dissolving powers of a soft water for city

* *J. Soc. Chem. Ind.*, vii. 15.

supply is to admit to the reservoir or mains a suitable quantity of pure, temporarily hard spring-water. The amount of such spring-water required would depend upon its composition, but would be probably very small.

Another remedy is to allow the entering water to flow over a bed of marble or limestone.

Zinc.—Pipes of galvanized iron or of brass are now so largely employed for carrying water that the possibility of the zinc being attacked has become an important question.

Haines reports the presence of large quantities of zinc in water from a deep rock-drilled well near Philadelphia.* The outer casing, as well as the inner tube, is of galvanized iron. The water contained:

Free ammonia	4.73
Albuminoid ammonia	.08
Chlorine	8.
Nitrates	trace
Zinc	53.7
Total residue	155

Note that the nitrates probably present originally in the water have been reduced by the "zinc-iron couple" to ammonia.

A similar case of reduction is given by Heaton.†

The spring-water forming the public supply of Cwmfelin is carried through half a mile of galvanized-iron pipe. The influence of such carriage upon the character of the water is shown by the analyses here quoted:

	At Spring.	At Delivery.
Free ammonia	none	.114
Nitrogen as nitrate	.8	none
Total residue	154.3	270
Zinc carbonate	none	91.6

* *J. Fk. Inst.*, Nov. 1890.

† *Chem. News*, xlix. 85.

An examination made by the writer of a rain-water which had been stored in a galvanized-iron tank during four and a half months showed 20.9 parts metallic zinc per million of water.

Howe and Morrison,* while experimenting upon a hard water containing much lime and magnesia and also much carbon dioxide, but no sulphates and no chlorides, found that it acted strongly upon brass, dissolving out the zinc.

Action upon lead was also pronounced, the hardness of the water offering no protection to the metal.

In the absence of air a slight action upon iron was observed which greatly increased when air was admitted.

The water did not attack either aluminum or nickel.

As in the case of lead, it is better to experimentally determine the action of a given water upon zinc, rather than to attempt to predict the same from a knowledge of the composition of the water.

Unlike lead, zinc is not a cumulative poison, therefore the presence of the metal in very small quantities is not so objectionable. There are not a few authorities who claim that zinc-poisoning, through the use of water, has not been proven, although P. F. Frankland reports such a case arising from the use of water from a shallow, sewage-polluted well. Waters from such wells were long ago shown to act quickly upon zinc.†

In the *Analyst*, iv. 51, is a report of an analysis of the spring-water supply of Tuttendorf, Germany. The zinc present corresponds to .007 part of the oxide per million, yet this water has been in use a century.

With reference to the action upon health of the Cwmfelin supply, spoken of above, no report is forthcoming.

The great insolubility of those compounds of zinc commonly formed by the action of water upon the metal constitutes a material safeguard in its use.

* *J. Am. Chem. Soc.*, xxi. 422.

† Rivers Pollution Commission, 6th Report.

Dr. Boardman * believes that oxide of zinc, as it occurs in drinking-water, is absolutely harmless. He says the same of the carbonate. As to salts in solution, he adds: "Admitting, then, that water which has been stored in reservoirs or drawn through pipes of galvanized iron always contains zinc in solution, in the form of one or more of its salts, the innocuity of those salts, in the quantities in which they occur, is attested by the experience and experiments of distinguished observers."

He further says: "At least with water fit for drinking purposes in other respects the contained zinc salts in solution do not exert any deleterious effects upon the human system. Even if all the zinc in solution were in the form of chloride, the most active poison of the zinc salts, the amount would still be insufficient to endanger health." †

However willing most of us may be to agree with the doctor in his first remarks, it would be doubtful policy to follow him to the extent of this final statement.

There is reason to believe that certain waters can furnish dangerous quantities of zinc, and the use of galvanized iron for transmission of a water-supply should not be decided upon until examination has shown the water in question to be without material action upon the zinc coating.

Iron.—When present, this metal is ordinarily in the water before it enters the distributing-mains, and is not a result of action upon the iron pipes. Chalybeate waters commonly hold the iron in solution as a carbonate, and less frequently as a sulphate.‡ Inasmuch as $\frac{1}{4}$ grain of the metal per gallon will

* Report Mass. Board of Health, 1874.

† Although small doses of the chloride have killed, very large doses have been followed by recovery. In one instance, known to the writer, a glassful of the solution was taken in mistake for Hunyadi water. Vomiting immediately ensued and very serious illness followed, but the final recovery was complete.

‡ A case of sulphate occurrence at Reading, Mass., is reported in *Engineering News* for June 4 and Nov. 26, 1896.

give a distinct taste, it would be difficult to make such a supply popular with the public, even were the water not unsuited to a variety of uses, such as dyeing and washing.

Such action as takes place upon the iron mains does not cause deterioration of the water carried in them, except in instances where the pipes lie empty a portion of the time, as when a surface pipe is drained in winter to avoid freezing. Iron corrodes very rapidly under such circumstances, and when the water is turned on again in the spring, the iron oxide stains it for a considerable time.

Cast-iron pipes corrode more quickly in water containing an admixture of salt; this is seen in the street-mains laid near the New York docks. "The life of a pipe is very short in such locality, and sixteen to twenty-five years is probably the limit of service." *

The following abstract from Trautwine deals with the special action of sea-water upon iron:

"Genl. Pasley examined cannon and other metal from the wreck of the Edgar, which had been sunk in sea-water for one hundred and thirty-three years, and reports that 'the cast iron had generally become quite soft, and in some cases resembled plumbago. Some of the shot, when exposed to the air, became hot, and burst into many pieces. The wrought iron was not so much injured, except when in contact with copper or brass gun-metal. Neither of these last was much affected, except when in contact with iron."

Very recently the writer received from Mr. W. C. Hawley, Superintendent of the Atlantic City Water Department, a piece of corroded cast iron which had been "blown out" from the side of a 12-inch force-main. No analysis has yet been made of it, owing to lack of time, but in appearance it resembles compact clay, yields to the knife like hard clay, is easily powdered in a porcelain mortar, and has a specific gravity of 2.28.

* *Jour. Am. Water-works Asso.*, xii. 27.

The following is from Mr. Hawley's letter: "The pipe has been laid about nineteen years under a salt meadow of deep black mud. Two separate layers of sound sod lie below the present surface grass.

"The action of this mud on steel or wrought iron is extremely severe. Wrought iron after fifteen or eighteen months looked as though it had been placed in strong acid, the fibre being brought out distinctly. The deterioration of the force-main ranged from one half to the full thickness of the metal."

H. M. Howe gives the following in his "Metallurgy of Steel":

LOSS OF WEIGHT IN POUNDS PER SQUARE FOOT OF EXPOSED SURFACE PER ANNUM.

	Exposed to the Weather Inland.		Immersed in		Average.
	Canada.	New York State.	Fresh Water.	Sewage.	
Wrought iron, black—i.e., unprotected	.0013	.0226	.1370	.1690	.0825
Cast iron, black—i.e., unprotected...........	.0063	.0120	.1483	.2724	.1066

There is a tendency with most waters to form what are known as tubercles upon the inside of iron water-mains. These are irregular projections, representing gradual accumulation, and consist largely of hydrated oxide of iron, at times mixed with some carbonate. The evil resulting from their presence is the material lessening of the delivering capacity of the main.

In a paper by Mr. James Duane in the Transactions of the Am. Soc. C. E. for January, 1893, the deductions are as follows:

"(1) An uncoated main conveying water of the general chemical composition of the Croton will become badly tuberculated in seven years, or probably much less.

"(2) That having reached a certain stage no further deterioration takes place.

"(3) That in a 48-inch main (uncoated) the discharging capacity is reduced about 30 per cent (by tuberculation); or, to put it another way, tar coating at present prices is worth about $20,000 per mile.

"(4) That a properly applied tar coating is an absolute protection against tuberculation, a 48-inch main after eleven years' service showing as high a coefficient as when first brought into use."

Exception was taken during the discussion of this paper to the statements concerning the arresting of the tuberculation process, for which the reader is referred to the original article. The "tar coating" is thus described in the *Engineering News*, September 26, 1895:

"Dr. Angus Smith patented his process in England about 1850, and it was applied to the first coated pipes used in the United States, imported from Glasgow in 1858. His 'coal-pitch varnish' is distilled from coal-tar until the naphtha is entirely removed and the material deodorized. He recommends the addition to this of from 5 to 6 per cent of linseed-oil. To coat the pipes, the pitch is heated in a suitable bath or tank to a temperature of about 300° F., and into this bath the pipes are immersed and allowed to remain until they, too, attain a temperature of 300° F. Mr. J. T. Fanning, in his "Water-supply Engineering," states that a more satisfactory method is to heat the pipes in an oven to about 310° and then immerse them in the pitch-bath, which is maintained at a temperature of not less than 210°. The linseed-oil has a tendency to float and separate from the pitch at high temperatures. An oil distilled from coal-tar is now more generally used. The pipes should be free from rust and absolutely clean before treatment."

Mr. de Varona's recent report upon additional water-supply

for the city of Brooklyn sets forth the excellent results observed from the use of a pipe-coating of which the main constituents are Trinidad asphalt and linseed-oil in certain proportions. The pipes, previously heated, are dipped in the coating-tank, whence they are taken out and baked in a vertical position during twelve or fourteen hours.

As replacing the old Bower-Barff process, by which a coating of magnetic oxide is deposited upon the hot metal, through the agency of superheated steam, according to the equation

$$3Fe + 4H_2O = Fe_3O_4 + 4H_2,$$

there has been introduced the Bertrand method, by which the same oxide is applied, but more after the manner of an enamel, and without that tendency to crack off which has always been an objection to the Bower-Barff coating for water-pipe.

The deposit referred to above as formed within iron water-pipe is commonly very adherent and correspondingly difficult to remove.

In France the experiment was tried, with entirely successful results, of piling the pipes in crib form with the spaces between filled with fuel. After a thorough burning the incrustation was found to be so disintegrated as to allow of its ready extraction.

Carbonic acid, as is well known, attacks iron easily; therefore the solvent character of a water containing much of it in solution must be expected.

Boilers may be affected by water in two ways, namely, through corrosive action of the water itself, or, indirectly, through the secondary evils resulting from scale formation.

Any free acid is objectionable in a boiler-water, even carbonic acid, if the quantity be large. In fact altogether too little attention is paid to the deleterious action upon the metal of the gases which the water may hold in solution. Carbon

dioxide and atmospheric oxygen jointly act upon iron at the boiler temperature with considerable energy, the equation being

$$2Fe + 2CO_2 + O_2 = 2FeCO_3.$$

The extent of such action may be most pronounced, especially in those parts unprotected by a coating of boiler-scale. The writer has observed very serious action, due to dissolved gases, upon the steam-pipes many feet from the boilers.

Sulphuric acid, so commonly present in mine-water, is highly objectionable. It is formed as follows from decomposition of iron pyrites:

$$2FeS_2 + 7O_2 + 2H_2O = 2FeSO_4 + 2H_2SO_4.$$

The liberation of free fatty acid by the steam acting under pressure * upon lubricating oils of animal or vegetable origin is another common cause of corrosion. For this reason it is preferable to employ a cylinder-oil of hydrocarbon character.

Water containing magnesium chloride is especially to be avoided for boiler uses, because the salt decomposes at the high temperature attained, with production of free hydrochloric acid; the equation being

$$MgCl_2 + 2H_2O = Mg(OH)_2 + 2HCl.$$

This acid being readily carried over in the steam, the damage that it works is not confined to the boiler alone.

It being known that ammonium chloride will prevent the decomposition of magnesium chloride, during evaporation, by forming therewith a stable double chloride, A. H. Allen suggests that the sodium chloride of sea-water acts in a similar way for the protection of marine boilers from the magnesium chloride found in sea-water. His remedy for stationary boilers

* The widely known "Tilghman patent" is an instance of such action.

compelled to use magnesium waters would be to add common salt to the feed-water.*

In view of the bad effects of magnesium chloride upon boilers, he further contends that it should appear in the analysis to the fullest extent compatible with the total amounts of chlorine and magnesium.

Water strongly alkaline with sodium salts, as is found in certain sections of the West, is also corrosive; for instance, such a water as that from Bitter Creek, Wyoming, which contains:

	Per Million.
Calcium carbonate	13.1
Silica (clay)	3.9
Calcium sulphate	trace
Sodium sulphate	431.0
Sodium carbonate	843.1
Sodium chloride	96.3
Silica (in solution)	8.6

Such a water could be purified for boiler purposes by the use of barium chloride; but another, and possibly cheaper, method under the circumstances is that employed by Mr. A. Pennell. He writes to the author: "Calcium sulphate is added, which forms sodium sulphate and precipitates calcium carbonate. A further dose of gypsum is then added, and the water is heated to 200° F., whereupon glauberite ($Na_2SO_4.CaSO_4$) precipitates as semi-transparent crystals. All does not precipitate at this temperature, but the rest falls at boiler temperature and is blown off at intervals."

Highly colored waters of "peaty" or swampy character, containing much organic matter, are often greatly corrosive to boilers. The writer had a marked case of such kind from a very deep drilled well in southern Alabama.

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* *J. Soc. Chem. Ind.*, vii. 800.

Boiler-scale may be classified as of two general kinds: first, that which is friable and mud-forming, such as is caused by the employment of temporarily hard water; and, second, a hard, compact, and adherent form, arising from the use of water of permanent hardness.

The hard adherent form is much the more objectionable, as a mud deposit is readily removed. The cause of the deposit of the calcium sulphate, which forms the compact scale, is found in the insolubility of that salt at the high temperature attained in the boiler. The curve of solubility shown on page 409 is seen to closely approach the zero line at a temperature of 150° C.

The writer possesses some hard, dense sulphate scale, of two inches in thickness, which was taken from the boilers of the steamer Tybee.

Although such a thickness is small compared with the mass "a foot thick" reported by Collet,* yet the heat arrested by such a deposit is ruinously wasteful of fuel.

Thus Rankine estimates † that the conductivity for heat of calcium carbonate is eighteen times, and of calcium sulphate is fifteen times, less than iron.

He holds that

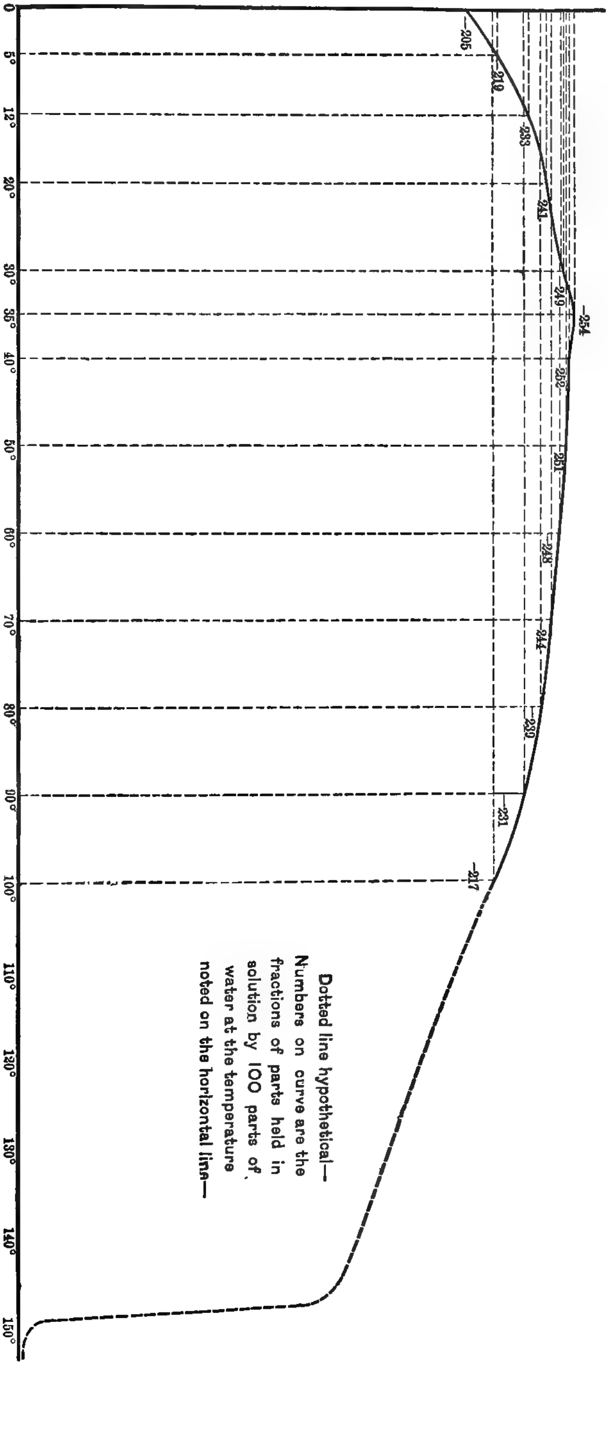
$\frac{1}{6}$-inch	scale	requires	16	per	cent	additional	fuel
$\frac{1}{4}$- "	"	"	50	"	"	"	"
$\frac{1}{2}$- "	"	"	150	"	"	"	"

Outside of waste of fuel, the damage to the boiler-metal resulting from the high temperature to which it must be heated in order to overcome the scale resistance must also be taken into consideration.

The deposit of the carbonates held in solution in temporarily hard water is caused by the escape of the solvent car-

* "Water Softening and Purification," p. 86.

† "Water Purification," Rideal, p. 201.



CURVE OF SOLUBILITY OF CALCIUM SULPHATE.

bonic acid gas upon the temperature of the water reaching the boiling-point.

Should means other than the elevation of temperature be employed for the removal of the carbonic acid in solution, the precipitation of the dissolved carbonates would take place with equal certainty.

Thus many years ago Dr. Clark patented a process, which still bears his name, for removing the carbonic acid by the use of lime-water, according to the equation

$$CO_2 + Ca(OH)_2 = CaCO_3 + H_2O.$$

The calcium carbonate formed by the equation precipitates, and along with it also fall the calcium and magnesium carbonates originally held in solution in the water by the CO_2 thus destroyed.

In America the "Clark process" for softening temporarily hard waters is not very frequently resorted to, because our waters are commonly fairly soft, or else are permanently hard, a form of hardness for which the process is not suited.

In England, however, where chalk deposits are so plenty, this method of purification is more often seen, and even on so large a scale as that required for a city supply. At Southampton the water for 63,500 persons comes from a large well in the chalk, sunk in 1888; and it is softened by a "Clark process" plant of a capacity of 2,000,000 gallons daily. The water receives a charge of 10 per cent of its volume of lime-water in a mixer and is then discharged into a softening cistern 38 × 23 × 3 feet. After partial precipitation, the milky water passes to perforated filter-plates covered with cloth. The cost of this plant was about $50,000. It produces 1½ tons of precipitate daily, and uses up ½ ton of lime for the purpose.*

* *Engineering*, March 11, 1892; see also *Engineering News*, April 16, 1892.

For boiler purposes the expensive filter-presses would not be warranted, and simple settling-tanks should be substituted.

Care should be taken to avoid the introduction of more lime-water than the reaction calls for, as a large excess would of itself cause a boiler-incrustation. The brown precipitate produced by pouring a solution of silver nitrate into lime-water is a convenient indicator for use with the Clark process. As soon as the said brown precipitate appears, in a sample of the treated water, upon addition of a few drops of silver nitrate solution, the further introduction of lime-water should cease.

The softening of permanently hard water may be accomplished by the addition of a solution of sodium carbonate, which causes a precipitation of insoluble calcium carbonate:

$$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4.$$

At times this reaction and the resulting precipitation take place in settling-tanks or filter-plants, but more commonly the equation is fulfilled in the boiler itself, and the non-adhesive mud is afterwards blown off.

"In England the London & Northwestern Railway has a plant at Liverpool which removes the hardness from over 200,000 gallons of water daily, and it has also a plant at Camden Town, London. The Taff Vale Railway has a plant at Penarth Dock, near Cardiff, treating 50,000 gallons daily, and removing both the carbonates and sulphates of lime and magnesium. The cost per 1000 gallons softened is stated as about 1.26 cents for the lime, soda, and alum used in the work." *

The cost of the "Clark process" is a somewhat difficult estimate to give in absence of local data, but it may be said that A. R. Binnie, engineer to the London County Council,†

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* This plant was described in *Proc. Inst. C. E.*, vol. xcvii. p. 354.

† See 1896 Report, page 22.

places the average first cost of such a plant at \$16,500 per million U. S. gallons daily capacity, and the yearly expense of working the same at \$1250.

Scale from sea-water consists mainly of calcium sulphate and magnesium hydrate; in fact, as Driffield has shown, magnesium occurs in these deposits as hydrate, although precipitated as carbonate, the conversion to the former being accomplished by the high temperature of the boiler.*

Such a change is more likely where the scale is in touch with highly heated metal, and it may be represented by the equation

$$MgCO_3 + 2H_2O = Mg(OH)_2 + CO_2 + H_2O.$$

A very large number of boiler-scale "preventives" and "eradicators" have been placed upon the market which are peculiar for nothing, as Professor Chandler has well said, except their high price. Such as have any value whatever may be duplicated, at very little expense, out of quite common materials.

Unfortunately many of these preparations are perfectly inert, and not a few are positively harmful. In the latter class, for instance, the writer has found such material as acid sodium sulphate colored with logwood. Such a perparation acts upon metals with half the intensity of pure sulphuric acid, and its continued use must surely work injury to the boiler. A large class of these "preventives" aim not at the actual prevention of a deposit, but rather seek to alter its physical character.

Thus many of them are of a mucilaginous order, and their action is to so envelop the precipitating particles of mineral matter as to prevent their mutual adherence. A further action of such of the compounds as contain insoluble material like

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* *J. Soc. Chem. Ind.*, vi. 178.

sawdust is to provide separated nuclei, about which crystallization of the scale-forming salts may occur. In the first instance, such an increase in the viscosity of the water may follow as to cause serious frothing or "priming," and in the second there is additional danger of getting solid substances carried over into the moving parts. It is very questionable if as desirable results can be obtained by the employment of any of the "eradicators" as may be had by the use of ordinary sodium carbonate, or, still better, sodium fluoride.

This latter salt, first suggested by C. A. Doremus, when introduced into the boiler accomplishes its work of rendering the deposit non-crystalline and non-adhesive, without causing the water to assume an alkaline reaction, as is the case when sodium carbonate is employed.

The precipitate formed is always amorphous.*

R. Jones obtains the best results for preventing boiler-scale by the use of sodium carbonate. He uses enough to constantly maintain the water slightly alkaline after filtration, i.e., it gives a distinct red with phenol-phthalein, a solution of which the boiler attendant always has at hand. The boiler is blown off daily from the highest to the lowest water-level.†

Mabery and Baltzley ‡ suggest the use of sodium aluminate, which acts as follows:

$$CaCO_3 + CO_2 + 3H_2O + Na_2Al_2O_4 = CaCO_3 + Al_2(OH)_6 + Na_2CO_3.$$

The sulphate being acted upon by the Na_2CO_3 formed:

$$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4.$$

They claim the best results by using one half the theoretic

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* *J. Am. Chem. Soc.*, xv. 610.

† *Chem. News*, lxvii. 185.

‡ *J. Am. Chem. Soc.*, xxi. 23.

quantity of sodium aluminate called for by the equation, and allowing sedimentation to take place for twenty-four hours.

Excellent results are obtainable from the use of an iron-zinc couple, secured by attaching plates of zinc to the boiler-bracings. Protection of the iron results at the expense of the zinc plates.

APPENDIX.

APPENDIX A.

ANALYSES OF CITY WATER-SUPPLIES.

	Free Ammonia.	Albuminoid Ammonia.	Chlorine.	N as Nitrites	N as Nitrates	"Required Oxygen."	Total Residue.
Cambridge, Mass., average 1893...	.106	.202	5.8	.006	.285	4.043	66.6
Fitchburg, " " " ...	.001	.233	1.7	0	.033	2.870	26.8
Haverhill, " " " ...	.003	.182	2.4	0	.020	3.669	27.3
Lynn, " " " ...	.039	.214	5.5	.001	.054	5.102	36.1
Springfield, " " " ...	.009	.204	1.5	.001	.026	5.132	37.6
Boston, " " 1894...	.006	.319	4.1	.001	.106	6.295	46.4
Burlington, Vt. (Lake Champlain)..	.035	.140	0.7	0	trace	1.525	70.0
Poughkeepsie, N. Y. (Hudson River)	.050	.125	4.5	trace	trace	2.287	85.0
Washington, D. C. (Potomac)......	.050	.127	1.1	trace	.230	1.021	165.0
Richmond, Va. (James River)......	.550	.150	1.17	trace	trace	1.654	105.0
Rock Island, Ill. (Mississippi R.)...	.025	.260	1.00	0	trace	6.000	140.0
New Orleans, La. (Mississippi R.)..	.040	.325	14.50	0	.080	5.724	340.0
Charleston, S. C. (Artesian well)...	.300	.040	130.00	.368	0	2.043	1170.0
Brooklyn, N. Y. (Ground-water)....	.001	.085	13.5	0	16.0	.....	64.0
Cincinnati, O. (Ohio River)........	.003	.108	14.0	.....	.26	.....	140
Philadelphia (Schuylkill River, average of 22)......................	.010	.100	......	0	.46	.....	133.4
Albany, N. Y. (Hudson River)......	.070	.200	2.5	trace	.082	5.7	......
Troy, N. Y. (Hudson River)........	.040	.150	2.5	0	.041	8.4	......
Cohoes, N. Y. (Mohawk River).....	.060	.210	4.0	.002	.246	3.55	......
New York, weekly average for 1894	.012	.082	2.47	0	.258	.....	81.6
Extreme variations of same........	.005 to .025	$\{$.025 .175	$\{$2.04 2.89	0	$\{$.111 .489	.....	$\{$67. 97.
Paris (Vanne water, average for 1894)	...	.....	6	.....	2.22	.8	254

APPENDIX B.

AVERAGE ANNUAL TYPHOID FEVER DEATH RATES PER 100,000 POPULATION, FOR THE YEARS 1898, 1899, 1900, IN CITIES OF THE UNITED STATES OF OVER 30,000 POPULATION.

AS REPORTED BY THE "COMMITTEE ON THE POLLUTION OF PUBLIC WATER SUPPLIES" OF THE AMERICAN PUBLIC HEALTH ASSOCIATION, AT THE BUFFALO MEETING, SEPTEMBER, 1901.

City.	Av.	City.	Av.	City.	Av.
Akron, Ohio	29	Grand Rapids, Mich.	36	Portland, Ore.	28
Albany, N. Y.	79	Hartford, Conn.	47	Providence, R. I.	24
Altoona, Pa.	33	Harrisburg, Pa.	41	Quincy, Ill.	35
Allegheny, Pa	86	Haverhill, Mass.	18	Reading, Pa.	50
Allentown, Pa	49	Hoboken, N. J.	21	Richmond, Va.	55
Atlanta, Ga.	55	Holyoke, Mass.	21	Rochester, N. Y.	17
Auburn, N. Y.	28	Houston, Tex.	33	Rockford, Ill.	5
Augusta, Ga.	34	Indianapolis, Ind.	38	St. Joseph, Mo.	19
Baltimore, Md.	35	Jersey City, N. J.	24	St. Louis, Mo.	23
Bayonne, N. J.	21	Johnstown, Pa.	83	St. Paul, Minn.	23
Binghamton, N. Y.	51	Kansas City, Mo.	31	San Antonio, Tex.	67
Birmingham, Ala.	45	Kansas City, Kans.	46	San Francisco, Cal.	37
Boston, Mass.	30	Knoxville, Tenn.	88	Saginaw, Mich.	25
Bridgeport, Conn.	14	Lancaster, Pa.	59	Salem, Mass.	23
Brockton, Mass.	24	Lawrence, Mass.	25	Salt Lake City, Utah	30
Buffalo, N. Y.	27	Lincoln, Neb.	18	Savannah, Ga.	34
Butte, Mont.	40	Little Rock, Ark.	58	Schenectady, N. Y.	21
Cambridge, Mass.	18	Los Angeles, Cal.	43	Scranton, Pa.	23
Camden, N. J.	33	Louisville, Ky.	60	Seattle, Wash.	32
Canton, Ohio	40	Lowell, Mass.	21	Sioux City, Iowa.	23
Charleston, S. C.	122	Lynn, Mass.	20	Somerville, Mass.	20
Chattanooga, Tenn.	67	Malden, Mass.	16	South Bend, Ind.	35
Chelsea, Mass.	24	Manchester, N. H.	19	Spokane, Wash.	57
Chester, Pa.	64	Memphis, Tenn.	33	Springfield, Ill.	44
Chicago, Ill.	28	McKeesport, Pa.	53	Springfield, Mass.	26
Cincinnati, Ohio	35	Milwaukee, Wis.	18	Springfield, Ohio	44
Cleveland, Ohio	40	Minneapolis, Minn.	39	Superior, Wis.	63
Columbus, Ohio	31	Mobile, Ala.	62	Syracuse, N. Y.	31
Covington, Ky.	39	Montgomery, Ala.	54	Tacoma, Wash.	25
Dallas, Texas	47	Nashville, Tenn.	46	Taunton, Mass.	25
Davenport, Iowa	32	Newark, N. J.	22	Terre Haute, Ind.	57
Dayton, Ohio	30	Newton, Mass.	20	Toledo, Ohio	32
Denver, Colo.	38	New Bedford, Mass.	30	Topeka, Kans.	43
Des Moines, Iowa.	21	New Haven, Conn.	30	Trenton, N. J.	36
Detroit, Mich.	19	New Orleans, La.	54	Troy, N. Y.	101
Dubuque, Iowa	23	New York, N. Y.	19	Utica, N. Y.	22
Duluth, Minn.	62	Norfolk, Va.	64	Washington, D. C.	68
Elizabeth, N. J.	13	Oakland, Cal.	23	Waterbury, Conn.	40
Elmira, N. Y.	43	Omaha, Neb.	28	Wheeling, W. Va.	82
Erie, Pa.	28	Paterson, N. J.	35	Wilkesbarre, Pa.	29
Evansville, Ind.	60	Pawtucket, R. I.	23	Wilmington, Del.	48
Fall River, Mass.	15	Peoria, Ill.	24	Worcester, Mass.	18
Fitchburg, Mass.	21	Philadelphia, Pa.	54	Yonkers, N. Y.	11
Fort Wayne, Ind.	31	Pittsburg, Pa.	108	York, Pa.	83
Galveston, Texas.	67	Portland, Me.	46	Youngstown, Ohio	105

APPENDIX C.

Mr. J. W. Hill has collected the following statistics, showing deaths from typhoid fever per 100,000 inhabitants:

AMERICA, 1894.

New York	17	Philadelphia, Pa.	32
Brooklyn	15	Chicago, Ill.	31
Newark, N. J.	15	Baltimore, Md.	48
Detroit, Mich.	26	Washington, D. C.	71
Cleveland, O.	27	Pittsburg, Pa.	56
Boston, Mass.	28	Buffalo, N. Y.	36
Dayton, O.	20	San Francisco, Cal.	35
Milwaukee, Wis.	26	Cincinnati, O.	50
New Orleans, La.	28	Louisville, Ky.	72
Toronto, Can.	17	Providence, R. I.	47
Lawrence, Mass.	30	Jersey City, N. J.	76
St. Louis, Mo.	31	Lowell, Mass.	55

EUROPE, 1893.

London, Eng.	16	Munich	15
Manchester, Eng.	25	Trieste	17
Edinburgh, Scot.	14	Vienna, Aus.	7
Glasgow, Scot.	20	Budapest, Hun.	15
Paris, France	25	Brussels, Bel.	27
Amsterdam, Hol.	16	Venice, It.	26
Rotterdam, Hol.	5	Rome, It.	34
Hague, Hol.	2	Turin, It.	29
Copenhagen, Den.	9	Liverpool, Eng.	53
Stockholm, Swe.	8	Dublin, Ire.	87
Christiania, Nor.	6	St. Petersburg, Rus.	51
Berlin, Ger.	9	Moscow, Rus.	40
Hamburg, Ger.	18	Prague, Boh.	36
Dresden, Ger.	4½	Milan, It.	62
Breslau, Ger.	10		

APPENDIX D.

WEIGELT records the following observations of the effects upon fish of waters contaminated with products of industrial waste: *

Contained in One Million Parts of Water.	Kind of Fish Used.	Observations.
70 slaked lime, $Ca(OH)_2$..........	Trout.	Dead in 26 minutes.
1000 soda, $Na_2CO_3 . 10H_2O$......	"	After 3 minutes, restless.
0.5 chloride of lime, $CaCl_2O$......	"	Dead in 3 hours.
100 hydrochloric acid, HCl.......	"	On its side in 4 minutes.
100 sulphuric acid, H_2SO_4.... ...	"	On its side at once.
50 ammonia, NH_3...............	"	Dead in 47 minutes.
100 sodic arsenate $Na_2AsO_4 . 12H_2O$	"	Strong effect.
50 mercuric chloride, $HgCl_2$......	"	Dead in 54 minutes.
1000 calcium chloride, $CaCl_2$......	"	An effect in 2 hours.
100 green vitriol, $FeSO_4 . 7H_2O$...	"	Dead in 5 hours.
50 " " " ...	"	No effect in 16 hours.
1000 iron chloride, Fe_2Cl_6........	"	On its side in 3 minutes.
1000 manganese chloride, $MnCl_2$..	"	Speedy restlessness.
5 carbolic acid, C_6H_5OH...	"	Restless in 15 minutes.
1000 soap (unfiltered)............	Salmon.	Dead in 1½ hours.
1000 soap (filtered)..............	"	No effect.

* "Das Wasser," Fischer, p. 52.

APPENDIX E.

WATER FOR INDUSTRIAL PURPOSES.

BREWING.—The water should be very free from all decomposable organic matter; and from tannic acid infusions, such as might be obtained from a forest floor.

A good deep-seated water will serve the best. Although a soft water does well for porter and dark beers, because of its being a better solvent for coloring matter, yet for general purposes a certain amount of "permanent" hardness is preferable. "For pale ale there must be not less than 300 to 400 parts of $CaSO_4$ per million."

Those ingredients to be especially avoided are iron salts, sulphides, and high chlorides, especially magnesium chloride.

The following analysis, by Stolba, is of the water used for the celebrated Pilsner beer: *

Calcium sulphate	67 per million
Calcium carbonate	40 " "
Magnesium carbonate	33 " "
Iron carbonate	trace " "
Magnesium chloride	0 " "
Silica	22 " "
Organic material	trace " "
Sodium chloride	10 " "
Potassium chloride	trace " "
	172 per million

DYEING AND BLEACHING.—The water should be clear and soft. For the few dyes which are found to act better with a somewhat hard water, the hardness may be artificially created

* "Das Wasser," Fischer, p. 45.

as required. Iron salts are especially objectionable. They modify some colors, and leave stains upon light goods, particularly after contact with alkaline compounds.

The same objections hold good for salts of manganese. Hard waters decompose soap, often modify colors, and deposit insoluble calcium salts in the fibre.

A uniform water, distinguished from one of seasonal variation, is especially desirable, to permit of matching shades of color.

PAPER.—Clear, clean water is required, free from iron, which causes rust-spots.

SUGAR.—Nitrates are especially objectionable, as they interfere with the crystallization of the sugar.

APPENDIX F.

THE following definition of liquids which should be deemed polluting and inadmissible into a stream was formulated by the River Pollutions Commission of Great Britain (1886):

(*a*) Any liquid which has not been subjected to perfect quiet in subsidence-ponds of sufficient size for a period of at least six hours, or which, having been so subjected to subsidence, contains in suspension more than one part by weight of dry organic matter in 100,000 parts by weight of the liquid, or which, not having been so subjected to subsidence, contains in suspension more than three parts by weight of dry mineral matter, or one part by weight of dry organic matter in 100,000 parts by weight of the liquid.

(*b*) Any liquid containing, in solution, more than two parts by weight of organic carbon or 0.3 part by weight of organic nitrogen in 100,000 parts by weight.

(*c*) Any liquid which shall exhibit by daylight a distinct color when a stratum of it one inch deep is placed in a white porcelain or earthenware vessel.

(*d*) Any liquid which contains in solution, in 100,000 parts, by weight, more than two parts by weight of any metal except calcium, magnesium, potassium, or sodium.

(*e*) Any liquid which in 100,000 parts by weight contains, whether in solution or suspension, in chemical combination or otherwise, more than 0.05 part by weight of metallic arsenic.

(*f*) Any liquid which, after acidification with sulphuric acid, contains, in 100,000 parts, by weight, more than one part by weight of free chlorine.

(*g*) Any liquid which contains, in 100,000 parts by weight, more than one part by weight of sulphur, in the condition of either sulphuretted hydrogen or a soluble sulphuret.

(*h*) Any liquid possessing an acidity greater than that which is produced by adding two parts by weight of real muriatic acid to 1000 parts by weight of distilled water.

(*i*) Any liquid possessing an alkalinity greater than that which is produced by adding one part by weight of dry caustic soda to 1000 parts by weight of distilled water.

(*k*) Any liquid exhibiting a film of petroleum or hydrocarbon upon its surface, or containing in suspension, in 100,000 parts, more than 0.5 part of such oil.

To these standards was attached the proviso that "no effluent water shall be deemed polluting if it be not more contaminated with any of the above-named polluting ingredients than the stream or river into which it is discharged."

APPENDIX G.

THE USE OF SEA-WATER FOR STREET-WATERING, SEWER-FLUSHING, AND OTHER PURPOSES.

SUNDRY theoretical objections having been raised to the use of sea-water for such purposes, the following letters were obtained from officials of English seacoast towns, and were embodied in a paper by J. W. Cockrill, abstracted in *Engineering News*, Nov. 17, 1892.

Birkenhead.—"One spread of salt water on the surface of a street or road is equal to about three spreads of fresh water, as the latter under the heat of the sun evaporates, whereas the salt water leaves a crust on the surface and keeps down the dust for a considerable time. We have not yet flushed our sewers with salt water."

Hastings.—"Sea-water has been used in this town for some years for street-watering and sewer-flushing, and no inconvenience has been found to arise. There is, perhaps, rather more mud on the roads during the autumn, but, on the whole, I believe that sea-water has a good sanitary effect on both roads and sewers."

Worthing.—"Many of our streets are watered with sea-water, and have been for years. The effect upon roads is to bind them together almost like cement; dust is never seen on these roads when dry, and sea-water keeps damp at least as long again as fresh water. Such an argument as sea-water acting upon sewage so as to make it offensive is simply absurd."

Eastbourne.—"We thought of using sea-water some years ago, but as there was a general objection to it we gave it up. From what I have seen of its use, my opinion is that it materially assists the solidifying of a road."

Brighton.—"We do not use sea-water for street-watering, but we use it for flushing our main intersecting sewer, and if used in sufficient volume it is not offensive."

Blackpool.—"This corporation has used sea-water for street-watering and sewer-flushing for some time, and I find no complaints arise whatever, but sea-water makes sett-paving slippery."

Ryde.—"I can state confidently, after thirty years' experience in the use of salt water for watering roads, that, so far from deteriorating macadamized roads, it hardens the surface; so much so that during the recent dry summer we found that in streets with a gradient of 1 in 12, when it was necessary to water a second time in the day, we were compelled to use fresh water, otherwise the streets would have become too slippery. Doubtless, after a long course of salt water on a level road, when rain first comes the surface will be a little dirtier than if fresh water had been used. We find it pays to use salt water when a load of water costs twice as much as fresh. With reference to flushing sewers, I have had very little experience."

Rhyl.—"Sea-water will not injuriously affect macadamized roads, but have a good effect."

Torquay.—"I have used sea-water for street-watering upon macadamized roads for several years, and do not find any inconvenience; but if there is any difference between salt and fresh water, I think the salt water is preferable. I do not use salt water for flushing, except very rarely in the low level, and then I do not find any smell more offensive than at other times."

Margate.—"Had no special means of raising salt water, and so gave it up; when used, one load went as far as three loads of fresh water."

Plymouth.—"All the low levels are watered with it; consider that two loads of fresh water are not equal to one of salt."

South Shields.—"One load of salt water equals four loads of fresh."

Tynemouth.—"Has a very good effect upon street surface, as it hardens the surface of macadamized roads; we use it for watering, flushing, and baths."

Barrow-in-Furness.—"Use salt water for street-watering; when fresh water was used it took twice the quantity."

Ilfracombe.—"Used sea-water formerly, and contemplate doing so again. It retains its effect twice as long as fresh water, and it is very binding."

Gibraltar.—"A brackish water is used entirely for common purposes, and is supplemented by a very limited rain-water supply for drinking."

In addition to the foregoing, the following opinion of Mr. H. P. Boulnois may be quoted: "Watering the streets with sea-water should be adopted wherever it is feasible, as it not only gives a delightful freshness to the air, but it also causes the surface of the street to maintain its humidity for a longer period than when fresh water is used."

"The general results may be stated as follows: Since the construction of the works the consumption of water for street-watering has been annually less than 5,000,000 gallons at 5 cents per 1000 gallons, instead of 7,000,000 gallons at 24 cents per 1000 gallons as before."

"Used in sewer-flushing, salt water has cleaned them thoroughly, and after five years' experience no nuisance of any kind has followed. Its effect in the Yarmouth sewers has been to reduce and almost prevent the generation and accumulation of sewer-gas. Sewers can now be entered at once on the removal of the manhole cover, which was not the case before. An 18-inch pipe sewer on a gradient of 1 in 300 was formerly constantly clogged by deposits; it is now kept thoroughly clean by two flushes per day from a 3000-gallon tank, which fills the sewer two thirds full. There are no deposits of any

sort in the sewers, except in several of the larger ones, and there it has been reduced one half since salt water has been used. As to the effect of salt water on iron, the author says that the siphons are of galvanized sheet-iron only, but they have required no repairs since they were put in. As to the sulphates in sea-water, no evil effects are traceable; the town possesses no manufactories, and no acids are discharged into the sewers."

"The salt water has never been used for extinguishing fires, though it is available if needed. The author does not recommend it for this purpose, as he considers that a dwelling would not be habitable after its walls had been saturated with sea-water. It is used for private baths with satisfaction to the users."

INDEX.

SHORT-TITLE CATALOGUE

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